THE

JOHN MURRAY EXPEDITION

1933–34

BRITISH MUSEUM (NATURAL HISTORY)

THE

JOHN MURRAY EXPEDITION 1933–34

SCIENTIFIC REPORTS

VOLUME I

INTRODUCTION AND TOPOGRAPHY

LONDON:

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PLATES AND CHARTS

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ADDENDA ET CORRIGENDA

Page 1.—After Rear-Admiral J. A. Edgell, O.B.E., R.N., *for* " Hydrographer to the Admiralty " *read* " Hydrographer of the Navy ".

Page 2.—Line 2 from bottom, *for* " T. Cary Gilson " *read* " H. Cary Gilson ".

Page 3.—Line 14, *for* " Dr. Turky " *read* " Dr. Tourky ".

Page 6.—Line 21, *for* " T. Cary Gilson " *read* " H. Cary Gilson ".

Page 9.—Line 15 from bottom, *for* " turveying " *read* " surveying ", and line 10 from bottom, *for* " she " *read* " the ".

In Station List—Nature of Bottom—*for* " gr. " *read* " gn. " throughout.

At Station 75 *after* " G. 201 " *add* " OT. 201, 10.30 to 12.30 ".

At Station 143—Nature of Bottom—*for* " gr. " *read* " cr. ".

At Station 166—Nature of Bottom—*for* " rd. cl. ; m. nd.", *read* " rd. cl. ; mg. nd."

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VOLUME I, No. 1

INTRODUCTION AND LIST OF STATIONS

BY

LT.-COL. R. B. SEYMOUR SEWELL, C.I.E., SC.D., F.R.S., I.M.S.(ret.)

WITH FRONTISPIECE AND ONE CHART

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H.E.M.S. "MABAHISS."

[*Adlard & Son, Ltd., Impr.*

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WITH FRONTISPIECE AND ONE CHART.

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THE JOHN MURRAY EXPEDITION.

Committee.

Mr. J. C. Murray, President and Treasurer.
Professor J. Stanley Gardiner, F.R.S., Secretary.
Dr. E. J. Allen, D.Sc., F.R.S.
Dr. W. T. Calman, C.B., D.Sc., F.R.S.
Vice-Admiral Sir Percy Douglas, K.C.B., C.M.G., R.N. (ret.).
Rear-Admiral J. A. Edgell, O.B.E., R.N., Hydrographer to the Admiralty.
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Mr. D. J. Matthews.
Lieut.-Colonel R. B. Seymour Sewell, C.I.E., Sc.D., F.R.S., I.M.S. (ret.).

Scientific Staff.

Leader: Lieut.-Colonel R. B. Seymour Sewell, C.I.E., Sc.D., F.R.S., I.M.S. (ret.).
Deputy-Leader and Senior Chemist: Dr. E. F. Thompson.
Chemists: Mr. H. Cary Gilson.
Abdel Fatteh Mohamed Effendi.
Biologists: Dr. Hussein Faouzi, Director of Fishery Research, Coast-guard Administration, Alexandria.
Mr. T. T. Macan.
Surveyor and Navigator: Lieut.-Commander W. I. Farquharson, R.N.

Ship's Staff.

Captain K. N. Mackenzie.
Mulazim Awal Ahmed M. Badr (1st Mate).
Mulazim Awal Ahmed Sarwat (2nd Mate).
Chief-Engineer W. J. Griggs, M.I.Mar.E.
Mulazim Awal Mahmoud Mokhtar (2nd Engineer).
Mulazim Awal Edward Morcos (3rd Engineer).
Wireless Operator, Mr. Lloyd Jones.

The Crew, with the exception of the Carpenter and two temporary Firemen, who were taken on during the expedition to replace casualties, consisted of picked volunteers from the Coast-guard and Fisheries Service, Alexandria, Egypt.

A BRIEF NARRATIVE OF THE VOYAGE.

(*With Chart.*)

As a full account of the voyage will, it is expected, be published elsewhere, only a short account will be given here.

In order to render the "Mabahiss" suitable for the requirements of the expedition, a certain amount of structural alteration and refitting was necessary. The original laboratory, which was situated below deck amidships, was too small, and, in order to provide sufficient accommodation for both chemists and biologists, one cabin had to be sacrificed and was converted into the biological part of the laboratory; two single-berth cabins were converted into a two-berth cabin to accommodate the two Egyptian scientists, and the Scientific Officers' Mess Room was converted into a three-berth cabin for the three Cambridge scientists. The large Fish-Hold below the well deck was divided up; the after part was partitioned off to make an accessory Coal Bunker, capable of taking some 30 tons of coal in bags, and in the fore part a Refrigerator was installed and two Cold-storage Rooms constructed. An Echo-sounding Machine of the "Acadia" type was fitted to the ship, the recording apparatus being installed in the Chart Room on the Lower Bridge. The Upper Navigating Bridge was extended forward over the Hydrographic Winch and was fitted with an Anemometer; and a recording Mercury-Steel Thermograph was fitted to the "intake" of the Condensing Plant in the Engine Room. The after Trawling Gallows on the Port side was removed to make space for a spare propeller to be carried.

The "Mabahiss" was docked for refitting and alterations in the Egyptian Government Dockyard, Alexandria, early in July, 1933. Captain Mackenzie and Chief-Engineer Griggs were sent out to Egypt at the end of June in order to supervise the necessary work; and about the same time Mr. W. Tyler, of Messrs. Hughes Bros., was sent out by his firm to superintend the installation of the Echo-sounder.

The installation of the Refrigerator engine and the construction of the Cold-storage Rooms were supervised by Mr. Rey, who was sent down from Cairo for the work by Messrs. J. & E. Hall.

Lieut.-Commander W. I. Farquharson, R.N., and Dr. Thompson reached Egypt early in August, and Mr. T. Cary Gilson, Mr. T. T. Macan and myself arrived in Alexandria towards the end of that month.

Prior to our departure a reception was given to the members of the Expedition on board H.E.M.S. "El Amira Fawzia" by El Miralai Ahmed Fuad Bey, the Director of the Egyptian Marine, and the Director and Officers of the Egyptian Coast-guard and Fisheries Service; Captain Mackenzie, Lieut-Commander Farquharson and myself were also received in audience by His Majesty King Fuad.

Through the kindness of Captain Brooke Smith and the officials of the Meteorological Department of the Air Ministry, London, we were able to arrange for samples of the surface water to be taken, and correlated meteorological data to be recorded at regular times of the day for a period of one year along three definite routes across the Arabian Sea, namely between Aden and Karachi, Aden and Bombay and Aden and Colombo, or long. 80° E. in the case of vessels that did not call at Colombo, while through the kindness of the B.I. Steam Navigation Company, Ltd., a further series was taken between Bombay and Mombasa. All these samples and the data were sent to the University, Cairo, where the water-samples were analysed by Dr. Turky, under the supervision of the Dean of the Faculty of Science, Dr. D. H. Bangham.

Finally, thanks to the kindness of the Hydrographer to the Admiralty, it was possible to arrange for H.M.S. "Endeavour", under the command of Commander R. Southern, R.N., to carry out serial temperature observations and collect water-samples at a series of stations in the Arabian Sea, down the length of the Laccadive Sea and across the Indian Ocean to the south of the Bay of Bengal between Colombo and Penang.

The Expedition sailed from Alexandria on the morning of September 3rd, 1933, and, after calling at Port Said, proceeded through the Suez Canal. Our final departure from Suez (Port Tewfiq) was delayed till the 8th owing to the non-arrival of certain thermometers that were urgently necessary for work in the Red Sea. On the 9th we paid a visit to the Egyptian Marine Biological Station at Hurghada, and we then steamed south on our first cruise. On this cruise we were accompanied by Mr. Tyler in order that he might satisfy himself that the Echo-sounder was working satisfactorily. The weather was extremely hot and trying, largely due to a following wind, and in order to avoid overstraining the engine-room staff at the very outset of the Expedition, we anchored on successive nights off Jebel Zukhair Island (15th), Great Hanish Island (16th and 17th), and in Perim Harbour (18th). During the cruise we carried out observations at Stations A and 1 to 18, while subsidiary investigations were made from the motor boat in the bay on the west side of Great Hanish Island. We suffered from a series of mishaps. At Station 2, owing to the parting of a rope, we lost one of our heavy Bigelow sounding-tubes. At Station 3, when attempting to carry out a trawl in deep water of some 2094 metres, the Agassiz trawl got caught fast on the bottom, and, while attempting to heave it in, the chain holding the metre-wheel parted and the metre-wheel shot overboard, snapping the trawl-wire as it went; we thus lost the metre-wheel, an Agassiz trawl, and about 2800 metres of the trawl wire. We arrived at Aden on September 22nd, and sailed again on the 28th. Before we left the Chief Commissioner kindly provided us with a letter of introduction to the Head-men of the various Arab tribes along the coast that come within his sphere of administration, as well as a detailed statement of the general character and amenities of such places along the coast as he thought might be serviceable to us if we wished to anchor or land. The day before we sailed it was discovered that the ball-race of the ball-bearing in the Echo-sounder had seized, but fortunately we were able to replace it.

Our second cruise lay almost entirely in the Gulf of Aden, for we only left it to run out between Cape Guardafui and Socotra towards the south-east to make a deep station to the south-east of the island. Almost immediately after leaving port our refrigerator gave trouble, resulting in the total loss of our stock of fresh meat for the cruise. In attempting to rectify the fault our Chief-Engineer, Mr. Griggs, was badly gassed by the methyl chloride, on which the refrigerator worked, and we had to return to port and put him into hospital for a couple of days. We sailed again on October 3rd, and ran eastward down the Gulf and out into the Arabian Sea, where we carried out hydrographic work at Station 22 in 3556 metres, but an attempt to work a second deeper station further to the south-east had to be abandoned owing to a defect that developed in the hydrographic winch. We then turned westward and anchored for the night of October 7th in Ghubbet Binna Bay, on the north side of Ras Ali Bash Kil, on the African coast. The following day was spent in searching for a reported shoal-area, but without finding any trace of it, so we steamed back into the Gulf of Aden and anchored for the night of the 9th off the "Elephant Rock" on the African coast near Olach village. During the next week we carried out a series of stations across the mouth of the Gulf, as well as several trawls on both north and south sides. We returned to Aden on October 17th. During this cruise we carried out work at Stations 19 to 37. At Station 25 the trawl got caught in the bottom and the trawl-wire parted, resulting in the loss of a further 90 metres of trawl wire and another Agassiz trawl; and at Station 29 in a depth of some 2072 metres off the African coast the trawl appeared to get caught in a strong deep current that whirled it round and round, so that the trawl wire was looped round and round the net, that, of course, failed to fish. Our hydrographic observations here and in the south end of the Red Sea revealed an extensive circulation of the deep water-masses, especially near the mouth of the Gulf where the northward flow of the Socotra Current enters the Gulf between Cape Guardafui and Socotra; and the echo-sounder indicated that the bottom of the Gulf is very irregular, a series of ridges appearing to run out in a direction from NE to SW from the northern shore, while the southern part of the Gulf is occupied by a channel of over 2000 metres depth.

We remained at Aden from October 17th to 21st and then left on our third cruise, along the Arabian coast to Karachi. Before we left we received from Bombay 1000 fathoms of trawl-wire which the Director of the Marine Survey of India had very kindly sent us to replace the wire that we had lost. After working a series of hydrographic stations in a line along the centre of the Gulf we headed northward to the Arabian coast to the neighbourhood of the Khorya Morya Islands, where we stayed for two days, anchoring off Soda Island on the 27th and off Hallaniya Island on the 28th. On the 29th we steamed eastward, and, after investigating certain so-called coral-reefs, we anchored for the night of the 30th off Ras Madraka, and of November 1st off Ras Marqaz. On the 2nd, continuing our eastward course, we anchored off Lashkarah village, on the 4th off Ras Khabbah, and on the 5th off Ras al Hadd. We left the Arabian coast on the 6th and steamed eastward towards Karachi, where we arrived on the 10th.

During the cruise we carried out work at Stations 38 to 61, and in addition made some investigations from the motor-boat on the north side of Hallaniya Island in the Khorya Morya Group.

The south and south-east region of the Arabian coast possesses a very steep and rugged continental slope, that in one place at least seems to consist of a definite granite

scree-slope; we further discovered the existence of a zone between the depths of some 100 metres and 1300 metres in which there seems to be a complete absence of life, though above and below there is a varied and in places a rich fauna; throughout this area the bottom consists of a soft green mud, that in the neighbourhood of Cape Ras al Hadd is strongly impregnated with sulphuretted hydrogen gas. All along this coast there also seems to be a complete absence of true coral-reefs, those banks that we investigated, that had been recorded as coral-reefs, turning out to be in the main composed of Lithothamnion.

Throughout the cruise the spreading of the drum on the hydrographic winch had been giving a great deal of trouble, and on arrival in Karachi the drum was dismounted and was sent ashore to the workshops to be strengthened.

We left Karachi for a cruise round the Gulf of Oman on November 17th, and after running towards the south-west for twenty-four hours we turned to the north-west towards the Baluchistan coast, off which we attempted to carry out a trawl in 1704 metres, but the net apparently filled with the soft bottom mud, the rope strop on the trawl frame parted, and the whole net carried away from the foot- and head-ropes. We then worked our way westward along the Baluchistan coast into the Gulf, and then turned south to Muskat, where we anchored for the night of October 22nd, Captain Mackenzie and I paying an official call on the British Resident. We left the following day and, proceeding northwards, anchored on the 25th about 6 miles off Jask; we then worked our way up to the head of the Gulf and down the south side, anchoring off Dubat Dibah on the 26th, and off Khor Fakkan on the 27th. Finally, we returned to the vicinity of Cape Ras al Hadd, to carry out further investigations on the sulphuretted hydrogen impregnated mud, and then steamed towards Bombay, putting in work at several stations on the Indian continental slope before reaching port on December 8th.

During this cruise we carried out work at Stations 62 to 90. Our work showed that the azoic area extended eastward from the Arabian coast into the Gulf of Oman between the depths of some 250–600 metres and about 1500 metres, the upper limit varying on the two sides of the Gulf. The echo-sounder showed clearly that this region of the Arabian Sea is traversed by several submerged hill ranges; the first of these runs westward, parallel with the Baluchistan coast, while a second mountain range runs in a south-west direction towards Cape Ras al Hadd, but does not connect with that promontory, a gap of some 137 sea-miles intervening between them. On the south-east side of this second ridge lies a gully having a depth of some 3658 metres, which is 274 metres deeper than the general level of the floor of the Gulf; on its own south-east side this gully is bounded by a third mountain range that commences as a wide plateau off the Indian coast and narrows to a ridge at its south-western extremity.

We left Bombay for Mombasa on December 13th. On the 15th, at Station 92, after carrying out a trawl with the Agassiz net in 3722 metres, the wire parted and we lost about 690 metres of wire and the trawl; and on the 20th, while carrying out a series of hydrographic observations late in the evening, the hydrographic wire parted and we lost a string of six Ekman reversing water-bottles and fourteen thermometers. On Christmas Day we, so far as circumstances would permit, celebrated the occasion, and we also that day carried out a series of hydrographic observations in the greatest depth that we had then encountered, namely 5060 metres.

During the cruise work was carried out at Stations 91 to 102. We reached Mombasa late on the night of December 31st, and, as we were by the port rules unable to get a pilot

till next day, we anchored for the rest of the night and entered harbour at dawn on January 1st, 1934.

We left Mombasa again on January 9th, and proceeded at once to Zanzibar, in order to pay official calls on His Highness the Sultan and the British Resident before commencing work off this part of the African coast. During this cruise the weather was decidedly unfavourable; strong winds from the north-east and heavy seas were encountered. Although work continued, we were compelled to confine our attentions for a large part of the time to the waters of the deep channel that runs between Zanzibar and Pemba Islands and then turns northward between this latter island and the mainland; in consequence, we were able on most days to reach an anchorage for the night, namely, at Mkokotoni Harbour on the 11th, Chaki Chaki Bay on the 12th, Port George on the 13th, and Manza Bay on the 14th. We were compelled to return to Zanzibar on the 18th, in order to land several cases of malaria, including Mr. T. T. Macan, the disease having been contracted during our stay in Mombasa, and on the night of the 18th we anchored in Menai Bay at the south end of Zanzibar Island. The next day we steamed eastward and carried out a trawl in 1204 metres and then steamed further eastward in the teeth of a strong head wind till we were in a depth of 2931 metres, where, in spite of the weather, we succeeded in carrying out a trawl successfully. In consequence of the adverse conditions we then returned to the area to the west of Pemba Island and anchored in Kingoje Bay for the night of the 21st, and in Mkoani Channel on the 22nd and 23rd, finally returning to Zanzibar on the 24th. On our arrival in port Chief-Engineer Griggs and Mr. T. Cary Gilson were sent to hospital for a rest, in order that they might recuperate.

During this cruise we carried out work at Stations 103 to 126. The fauna proved to be a rich one, and by means of the echo-sounder we were able to obtain indications of two parallel submarine ridges that appear to commence in the vicinity of Malindi Point and run southward on the east side of Pemba Island.

On the morning of January 30th His Highness the Sultan of Zanzibar received Captain Mackenzie, the Egyptian Scientists and Officers and myself in audience, and on our return to the ship we sailed for the Seychelles. As Mr. T. T. Macan had not completely recovered, we were compelled to leave him behind.

After steaming a little to the south of east for some forty-three hours we started to carry out observations at Station 127 in a depth of 4091 metres; but almost at once the drum of the hydrographic winch cracked right across and all work had to be stopped. We then steamed eastwards towards the Seychelles, and in preparation for the next station the hydrographic wire was run off the hydrographic winch on to the small drum of the trawling winch, and we were then able to carry out work at two more stations before reaching the Seychelles on February 6th. We anchored in Port Victoria, Mahé, and took on board some 50 additional tons of coal, and left again on the 8th for Colombo, our track passing through Kardiva Channel in the Maldive Archipelago. The weather, fortunately, had moderated very considerably, and in spite of strong head currents we made good progress, reaching Colombo on the afternoon of February 22nd.

During this cruise we crossed the Carlsberg Ridge, the echo-sounder clearly showing that in this part the ridge is of a double nature, a deep gully of 3385 metres depth lying between two ridges that rise to a depth of approximately only 1650 metres. A trawl with the Monégasque net was carried out in the gully, resulting in the collection of some of the fauna of the ridge and several rock fragments.

We remained at Colombo from February 22nd till March 17th. Soon after our arrival the "Mabahiss" was fumigated by the Port Medical Authorities, and was then completely overhauled, refitted and repainted. While in Colombo I met the Representative of the Maldivian Government, and he very kindly undertook on behalf of his Government to provide a boat to enable me to detach a party, consisting of Major Glennie, R.E., of the Survey of India, who was joining the Expedition at this port, and Lieut.-Commander Farquharson, R.N., for Geodetic and Magnetic work in the Maldive Archipelago. Opportunity was taken, while we were in Colombo, of sending most of the Scientists to Kandy for a week's rest and change.

We left Colombo on March 17th, and steamed to the south-west to the deep channel that runs between the Maldive and Chagos Archipelagos. Having made a hydrographic station in the middle of the channel we steamed northwards to Addu Atoll, which we entered on March 22nd, anchoring in the north-east corner of the lagoon and landing Major Glennie for geodetic observations. We left again on the 23rd for Malé Atoll, carrying out observations at several stations on the way and landing Major Glennie for geodetic work in Kolumadulu Atoll on the 24th, while on the 26th night we anchored in Mulaku Atoll.

We reached an anchorage in Malé Atoll off Sultan's Island on the 27th ; that evening we were visited by several of the Ministers of State, and on the following day Captain Mackenzie and myself, accompanied by several members of the Expedition, were received in audience by His Highness the Sultan.

On the 28th we steamed northward to Fadiffolu Atoll, and anchored in the lagoon off Difuri Island that lies on the east side of the atoll rim. Here we landed our detached party, consisting of Major Glennie and his assistants, Lieut.-Commander Farquharson and some servants, and, leaving with them the motor-boat, we next morning steamed out from the lagoon into Kardiva Channel and carried out a trawl at Station 143 ; on the conclusion of this work we again entered the lagoon and anchored on the western side off Naifaro Island. Here we secured the Maldive boat, and the next day, having transferred our detached party to it, we left the atoll and anchored in the middle of Kardiva channel by a kedge anchor on the trawl wire in order to carry out observations for a period of twenty-four hours. Owing to Captain Mackenzie's ill-health, however, we were obliged to prolong our stay for a further period, and we then steamed westward and entered Horsburgh Atoll on April 3rd. During the next week, using Horsburgh Atoll as our base, we systematically explored the western slopes of the Maldives and the western end of Kardive Channel, while Dr. Thompson and Mr. Gilson, in the motor-boat, investigated the physico-chemical conditions in the lagoon. On the 8th we proceeded to South Malos Madulu Atoll and anchored in the lagoon, being rejoined the following morning by our detached party, that had made their way in the Maldive boat across the whole width of the Archipelago from east to west, making seven geodetic and ten magnetic stations.

On the 9th morning we took the Maldive boat in tow and steamed eastward to Fadiffolu Atoll, and then, having cast off the boat, turned northward to Minikoi, which we reached on the morning of the 9th. Here we landed Major Glennie for the last of his geodetic stations, and Mr. Gilson and Abdel Fatteh Mohamed Effendi carried out a series of observations in the lagoon. We left Minikoi on the 10th, and returned to Colombo, which we reached on the 13th, running a line of soundings *en route* across Wadge Bank.

During this cruise we carried out work at Stations 136 to 162, while Major Glennie

and Lieut.-Commander Farquharson carried out geodetic or magnetic observations respectively at ten stations. By means of the echo-sounder we were able to discover and map a submerged atoll, now lying at a depth of some 238 metres, at the west end of Kardiva Channel, and we have much pleasure in naming it "King Fuad Bank" in recognition of the interest that His Majesty has taken in the work of the Expedition. In the Channel and on the upper levels of the western slopes the fauna was rich, but as one passed to deeper levels down the westward slopes the fauna appeared to become decidedly poor, though this may to some extent be apparent, rather than real, owing to the difficulty of trawling successfully on a steep slope. There seemed to be indications of a strong deep current flowing across the Maldive Ridge through the channels.

We left Colombo on our homeward cruise to Aden on April 19th. At first we steamed through Kardiva Channel, in order to run another line of soundings across King Fuad Bank, and then turned northward till we were in about lat. 7° N., when we turned westward across the Arabian Sea. Having carried out work at several stations, including a deep trawl in 4793 metres, that resulted in our making a collection of 125 kilogrammes of Manganese nodules of various shapes and sizes but without discovering any trace of animal life, we again crossed the Carlsberg Ridge, and again obtained indications that the ridge is double with an intervening deep gully. An attempt to carry out a trawl on the ridge resulted in the Monégasque net becoming caught on the bottom, and the frame was badly bent and one of the stirrups smashed ; but entangled in the net were a few fragments of a foraminiferal limestone stained black on the outside, probably with manganese.

After crossing the ridge we steamed along its south-western side for some distance and then turned through the Socotra Channel and entered the Gulf of Aden, where we repeated the observations that we had made during our previous visit across the mouth of the Gulf, and carried out several trawls on both sides of the Gulf before we put into Aden on May 8th.

We left Aden for the last time on May 14th and steamed south in order to repeat our hydrographic observations along long. 45° E. Having completed work at these stations we turned westward towards the Straits of Bab-el-Mandeb to repeat our observations on the Perim section ; unfortunately Captain Mackenzie, whose health had been failing for some time, developed an attack of high fever and delirium, and all work had temporarily to be stopped, and we drifted for the night in the hope that by the next morning he would be better. Fortunately this was the case, and so we were able to complete the Perim section and repeat our observations through the Straits, as well as to carry out some trawls and hauls with the Grab in the southern part of the Red Sea. As Captain Mackenzie was still far from well, work was then stopped, and we steamed north with all possible speed to Suez, which we reached on May 21st, just before midnight.

Our work at the southern end of the Red Sea and in the Straits of Bab-el-Mandeb at two different seasons of the year showed that there are very distinct seasonal changes in the conditions present in this area ; and, further, it seems clear that at depths greater than that of the entrance channel, namely some 100 metres, there is an almost complete absence of animal life, while chemical changes, that are taking place on the bottom, are resulting in the formation of a calcareous rock in the brown mud of the bottom deposit.

We passed through the Suez Canal on the 22nd–23rd, and headed for Alexandria, which we reached on May 25th. On our arrival we were met by Mr. and Mrs. Murray, who had come out from England to greet us on our return, and by El Miralai Ahmed

Fuad Bey, and other officials of the Marine and Coast-guard Services. Two days later we were given a reception on board H.E.M.S. " Sollum ", and then, at the invitation of Cairo University, the members of the John Murray Expedition proceeded to Cairo, where a reception was held in our honour by Mohamed Hilmy Issa Pasha, the Minister of Public Instruction, and a day or two later we were received in audience by His Majesty King Fuad. Captain Mackenzie and Chief-Engineer Griggs returned to Alexandria in order to hand the " Mabahiss " back to the Coast-guard Administration, and the other members of the Expedition proceeded to Port Said, and on June 3rd sailed for England, reaching Plymouth on the 14th.

THE SHIP AND THE SCIENTIFIC EQUIPMENT.

The H.E.M.S. " Mabahiss " was built in 1929 by Swan Hunter & Wigham Richardson, of Newcastle-on-Tyne, England, for coastguard and fishery research work; she is a trawler of the " Mersey " type.

Length, B.P. feet	138.
Breadth ,,	23 6".
Displacement tonnage	618.
Draft, forward (loaded)	12 6".
,, aft ,,	14 6".
Fuel	Coal.
Speed (clean)	11 knots.
Capacity of bunkers	160 tons.
,, of water ballast	90 ,,
Range of wireless	300 miles.
Boats (3)	One 20-ft. life-boat. One 22-ft. motor life-boat. One dinghy.

The scientific equipment necessary for an oceanographic expedition has now become more or less standardized as a result of the experience of previous expeditions, fishery research vessels and other ships that have been employed more or less continuously in turveying the ocean bottom for cable companies, or investigating hydrographic conditions for the Admiralty or for foreign navies.

In fitting out the " Mabahiss " for the work of the John Murray Expedition full advantage was taken of the experience of the R.R.S. " Discovery ", and much of our apparatus was identical with that used by her in her Antarctic work. A full account of she various pieces of apparatus is, therefore, unnecessary, and for any desired information on this subject reference should be made to the ' Discovery Reports ', Vol. I.

The equipment carried by the " Mabahiss " was as follows :

One steam Windlass on forecastle.

One horizontal steam-driven Trawl Winch on the well deck.

This winch has two drums, (i) for 4000 fathoms of wire and (ii) for 1000 fathoms of wire, and two rope holders.

One steam-driven Hydrographic Winch, on the lower bridge.

This has two drums, (i) for 3000 fathoms of wire and (ii) for 1000 fathoms of wire.

One light steam-driven Warping Winch aft.
One Lucas steam-driven Sounding Machine on poop.
This will take 3000 fathoms of sounding wire No. 22 gauge.

Trawling Wire . . . (i) 3500 fathoms of tapered wire, $1\frac{3}{8}$–$1\frac{3}{4}$ in. cir.
(ii) 1500 ,, ,, $1\frac{1}{8}$–$1\frac{1}{2}$ in. ,,
(obtained later to replace loss).

Hydrographic Wire, 4 mm. . . . (i) 3500 fathoms on large drum.
(ii) 2000 ,, } to replace loss.
(iii) 2735 ,, }
(iv) 275 ,, on small drum.

Lucas Sounding Wire	3 reels.
Castor Oil and Tallow mixture for greasing wires	20 gallons.

This was used for the trawling wire and proved to be quite satisfactory.
A heavy oil was used for the hydrographic wire.

Measuring Sheaves : heavy for trawl wire	1
(a second was ordered later to replace loss)	
light for hydrographic wire	2
Swivel Shackles: heavy, 5-ton strain	2
(two ordered later to replace loss)	
light, 2-ton strain	2
Stops for attachment of tow nets to trawl wire	8
Self-closing Mechanism for large plankton net	1
Stream-line Weights and Bars	3

Apparatus for Examination of Sea Floor.

Admiralty Recording Echo-Sounding Machine, Acadia type	1
Baillie Sounding Rods	13
Weights for above, "cones"	200
"flats"	200
Driver Sounding Rods*	2
(a third ordered later to replace loss)	
Weights for above, 50 lb.	100
Glass tubes for above	100
"Bigelow" type Sounding Rods, heavy	2

In this type of sounding rod the tube is made in two sections. The upper section consists of a length of galvanized tubing of 2 in. diameter and 4 ft. in length ; at the top end is fitted a shackle for attachment of the rod to the hydrographic wire, and the bottom end is provided with a screw thread for the attachment of the bottom section ; a stream-line weight of 100 lb. is fixed to the lower end of this section. The lower section consists simply of a length of galvanized tubing, which screws into the top section and at the lower end is bevelled into a cutting edge ; two lengths of lower section were carried of 3 ft. 6 in. and 5 ft. respectively. Cores up to 5 ft. in length were obtained with this apparatus.

Grab, of a modified "Petersen" type, area ½ sq. metre	1
Conical Dredge, mouth 16 in. diameter, circular, with canvas bag	2
Snapper Leads, of ordinary pattern	2
,, of disengaging pattern	2
,, cast-iron sinkers for above, 50 lb.	12
30 lb.	12

* This type of sounding rod is described in the 'Discovery Reports', Vol. I, p. 211, under the name "Ekman-Nansen Sounding Rod".

For use with the Motor-boat:	
Small Lucas Sounding Machine (worked by hand)	1
Bigelow type Sounding Rods, light	2

In this smaller size the length of the top section was 2 ft. and the diameter $\frac{3}{4}$ in., the weight being 10 lb.; the bottom section was in two sizes, one of 18 in., and the other 2 ft. 6 in. in length.

Hydrographic Apparatus.

Nansen-Petterssen Insulated Bottles	2
Ekman Reversing Water-bottles, ordinary pattern	8
,, ,, with silver-plated barrels	3
,, ,, fitted for three thermometers	3
,, ,, ditto to replace losses	3
Reversing Thermometers, unprotected	3
,, ,, ordered later to replace losses	2
,, ,, protected	25
,, ,, ditto to replace losses	3
Depth Gauges, (i) for 1000 fathoms	1
,, (ii) ,, 2500 ,,	1
Ekman Current Meter (lent by the Admiralty)	1
Secchi Disc	1
Mercury-Steel Thermograph (in Engine Room)	1

*Meteorological Apparatus.**

Anemometer (fixed on upper bridge)	1
Asman Psychrometer, with spare thermometers	1

Biological Equipment.

Otter Trawl, head rope 40 ft., complete	2
Agassiz Trawl, width 3 metres	3
,, ,, obtained later to replace loss	2
,, ,, spare nets	2
Monégasque Trawl, width 7 ft.	1
"Salpa" pattern Dredge,† width 4 ft.	2
,, ,, ,, 3 ft.	2
,, ,, ,, 2 ft.	2
Triangular Dredge, each side 4 ft.	2
,, ,, ,, 3 ft.	2
,, ,, ,, 2 ft.	2

In the case of both the "Salpa" Dredges and the Triangular Dredges, the smaller ones with a side 2 ft. were too small to be of any use for dredging from the ship, and, though originally intended for use with the motor-boat, were too heavy and could not be towed by the boat.

Large Plankton Net, 2 metre diam. circular mouth with stream-line ring and net with graded mesh	1
Spare Net	1
Plankton Net, 1 metre diam. circular mouth, net made of "stramine"	6
Plankton Net, 50 cm. diam. circular mouth, net made of fine silk	2

* This equipment was kindly lent by the Air Ministry, London.

† This pattern is made by the Marine Biological Association, Plymouth.

High Speed Plankton Net	1
Harvey Net,* for phytoplankton	1
Rectangular Dredge, width 18 in. (for use with the motor-boat)	1
Hand Net, with silk bag	2

Apparatus for the Preservation of Specimens.

Large Iron Preserving Tanks (on deck)	2
These proved to be unsatisfactory owing to the difficulty of keeping them water- and air-tight.	
Copper Tanks in wooden cases	6
These were kindly lent to the Expedition by the British Museum (Natural History).	
Large Stoneware Jars, 3-gallon capacity	11
Kilner Jars, in special fitted boxes, assorted sizes :	
½ lb.	4 gross.
1 lb.	4 ,,
2 lb. (squat)	2 ,,
5 lb.	2 ,,
7 lb.	1 ,,
Assorted glass tubes with flat bottoms of numerous sizes.	

Apparatus for the Examination and Storage of Water Samples.

Leather Buckets	2
Centrifuges, of two sizes	2
Aspirator Pump	1
Aspirator Bottles and Funnels	2
Comparator, for pH estimation	1
,, for phosphate determination	1
Spring-Stoppered bottles in cases (each containing 50 5 oz. bottles)	40 cases.
Waxed Water Sample Bottles in cases (each containing 50 bottles)	2 ,,

A full supply was carried of all necessary Burettes, Chemicals, etc., for complete analyses of the water samples.

In addition to the above equipment, the "Mabahiss" also carried a complete set of the necessary instruments for conducting a Magnetic Survey, these having been lent to the Expedition by the Admiralty, Whitehall; and Major Glennie, R.E., who joined the ship at Colombo, brought with him his apparatus for carrying out pendulum observations on the value of gravity.

METHODS OF PRESERVATION, ETC.

The anæsthetic most commonly employed was menthol, crystals being sprinkled on the surface of the sea-water in the bowl in which the animals were lying. This method was used as a routine in almost all cases of Actiniaria, Madreporaria, Alcyonacea, Gorgonacea, Penatulacea, Hydroids, Polychæta, small Holothurians and Nudibranch Molluscs.

* This net has been fully described by its inventor in the 'Journal of the Marine Biological Association', Vol. XIX, p. 761, 1934.

Gastropods were treated with magnesium sulphate, a handful of crystals being added to the sea-water in the bowl. The results obtained varied very considerably, but in some cases were quite satisfactory. Owing to the high temperatures that exist in tropical regions it is often very difficult to obtain complete anæsthetization before decomposition sets in.

For preservation either neutral formalin, alcohol, or a mixture of the two was employed ; in a few cases where special preservation was desirable Bouin's fluid was used. All fleshy animals, such as Medusæ, were preserved at once in formalin, with on the whole satisfactory results ; but in some cases, such as *Porpita* and large Ctenophores, Beroe, etc., no method could be discovered that would preserve these animals, disintegration taking place the moment the animal was introduced into the preserving medium.

For those animals in which calcareous spicules might be damaged by an acid reaction of the medium used, preservation was carried out by means of alcohol after a comparatively short treatment with formalin, and in these cases the process was carried out in stages, an immersion for some 24 hours in weak alcohol (approximately 70%) intervening between the primary immersion of the specimen in formalin and its final transference to strong alcohol of about 96% strength. The spirit used on board was supplied by the Colonial Sugar Refining Co., Sydney, Australia.

Sponges, Echinoderms and Crustacea were preserved directly in spirit, being placed at once in a rather weak (approximately 70%) solution, and then after some 16–20 hours transferred to full strength spirit, which was again changed after a day or two, and was finally changed a third time when the specimens were finally stowed away in the wooden cases for shipment to England. It was found, however, that this method of preservation in weak spirit was not satisfactory for fish, owing to the rapidity with which decomposition set in, and after the first month or so we used a mixture of 70% spirit mixed with a 1 in 8 strength formalin solution ; an incision was made into the peritoneal cavity on one side, and by means of a syringe some of the fluid was forced down the œsophagus into the stomach, while in large and fleshy examples more of the fluid was injected into the muscular tissues by means of a hypodermic syringe. After immersion for some 24–48 hours in this mixture the specimen was transferred to pure spirit of full strength..

Tow nettings were, as a rule, preserved in bulk by the addition of neutral formalin, and subsequently larger specimens, such as fish, prawns, etc., were picked out and were transferred to spirit and were preserved in separate tubes.

For the investigation of the Phytoplankton hauls were made by means of the Harvey net, and the catches were carefully preserved by the addition of neutral formalin ; while at four stations large samples of the sea-water were collected from various depths and were preserved by the addition of a suitable quantity of formalin for subsequent examination.

For the purpose of storage small specimens were usually placed in tubes or bottles. Flat-bottomed tubes of various sizes were used, and these were plugged after the introduction of the specimens by means of a plug of tissue paper and then by a cotton-wool plug, the tissue paper serving to prevent the specimen or specimens from getting entangled in the fibres of the cotton-wool ; the tubes were then stored in jars of suitable sizes. For the preservation of extra long specimens large flat-bottomed tubes of $1\frac{1}{2}$ in. by 12, 18 or 24 in. length were used, and these were plugged by corks, and the cork and upper end of the tube were then carefully waxed over.

All the jars used were supplied by Messrs. Kilner Bros., and were of the type commonly in use for preserving fruit.

The sizes used were ½ lb., 1 lb., 2 lb. squat, 5 lb. and 7 lb., and these were stored in special wooden boxes fitted with partitions and lined with felt ; the metal screw cap that clamps the glass top down on the rubber ring was made of copper instead of brass, in order to avoid rust. For still larger specimens earthenware jars of some 3-gallon capacity were used or special copper tanks in wooden boxes were used ; these latter were very kindly supplied to the Expedition by the British Museum (Natural History).

Two large storage tanks made of cast iron for extra large specimens were sent out and were installed in the ship on deck ; but it was found that these were very unsatisfactory. The heavy lid, which fitted down on to a rubber washer, and was clamped in position by a number of bolts fitted with " butterfly " nuts, could only be taken off or put on again with a great deal of trouble, and it was further found to be almost impossible to render the joint water-tight or air-tight. The spirit in the tank thus rapidly became weaker till it was too dilute to act as a preserving medium, and in addition the almost constant rolling or pitching of the vessel caused the specimens to be washed to and fro to such an extent that the muslin or cheese-cloth, in which the specimens were wrapped, was by the friction reduced to shreds and worn through, while the linen tags on which the data regarding the specimens were written in indian ink were reduced to fragments. So the use of these tanks was early discontinued.

Whenever time permitted, notes on or a water-colour sketch of any particularly interesting specimen were made ; but as we carried no artist, only very few of the latter could be done. When possible, notes on the colour of specimens were taken, and all colours were matched from Ridgway's ' Colour Standards and Colour Nomenclature ', usually in bright sunlight.

STATION LISTS

INTRODUCTION.

The following lists contain the details of the various stations made by the John Murray Expedition; the first list, in which the stations are numbered consecutively, refers to the stations made by the *Mabahiss*, and the second small list gives the biological stations that were made by the Motor-boat.

Positions in the first list are given in Latitude and Longitude.

The times given are " ship's time ", corresponding nearly with local zone time.

The depths given are in nearly all cases those actually shown by the echo-sounding apparatus, corrected for temperature and salinity. The abbreviations used in denoting the character of the bottom are as follows:

blk.	black.	gy.	grey.	r.	rock.
br.	brown.	h.	hard.	rd.	red.
c.	coarse.	lt.	light.	s.	sand.
cl.	clay.	lth.	lithothamnion.	sft.	soft.
cm.	cream.	m.	mud.	sg.	shingle.
cr.	coral.	mg.	manganese.	sh.	shells.
d.	dark.	nd.	nodules.	st.	stones.
gl.	globigerina.	oz.	ooze.	w.	white.
gn.	green.	pt.	pteropod shells.	y.	yellow.

The directions of wind, sea and swell are true bearings, and the strengths of the first two are respectively indicated by the terms used in Beaufort's scales, as given below:

Beaufort's Wind Scale.

Force.		Velocity.
0	Calm	..
1	Light airs	1–3 knots.
2	Light breeze	4–6 ,,
3	Gentle breeze	7–10 ,,
4	Moderate breeze	11–16 ,,
5	Fresh breeze	17–21 ,,
6	Strong breeze	22–27 ,,

Sea Disturbance Scale.

		Height of waves from crest to trough.
0	Calm glassy sea	..
1	Rippled sea	less than 1 foot.
2	Smooth sea	1–2 feet.
3	Slightly furrowed sea	2–3 ,,
4	Moderately furrowed sea	3–5 ,,
5	Rather rough, much furrowed sea	5–8 ,,
6	Rough, deeply furrowed sea	8–12 ,,

The barometer readings were taken by means of an Aneroid barometer and are uncorrected. The air temperatures were read in degrees Fahrenheit, and have been

converted into the Centigrade scale. In the column on weather the abbreviations and symbols used in the Admiralty Manual of Navigation have been employed; these are as follows:

b.	blue sky.	○	Clear sky.
c.	cloudy.	◐	Less than $\frac{1}{4}$ clouded.
l.	lightening.	◑	Sky $\frac{1}{4}$ to $\frac{3}{4}$ clouded.
o.	overcast.	◕	Sky more than $\frac{3}{4}$ clouded.
p.	passing showers.	●	Overcast sky.
z.	hazy, dust haze.		

In the hydrological observations all temperatures have been fully corrected. The salinity was determined by the estimation of the halogen-content of the water, and the subsequent conversion of these values by means of Knudsen's tables. In these lists only those hydrological observations have been given that are considered likely to be of most importance to specialists who are working on the faunistic collections; the full chemical and physical data will be published subsequently in an Appendix to the Chemical and Physical reports.

The following symbols are used to denote the type of gear used:

AT	Agassiz Trawl.
BR	Baillie Sounding Rod.
DC	Conical Dredge.
G	Grab of modified "Petersen" Type.
HN	Harvey Net for Phyto-Plankton.
MT	Monégasque Trawl.
N 100	Tow Net; mouth circular with diam. of 1 metre, of stramin.
N 200	Tow Net; mouth circular with diam. of 2 metres, of graded mesh.
NHS	High Speed Tow Net; of fine silk.
NS 50	Tow Net; mouth circular with diam. of 50 cm., of fine silk.
OT	Otter Trawl.
RD	Rectangular Dredge; width, 18 inches.
SD	Secchi Disc; diameter, 50 cm.
SD 3	"Salpa" Dredge; width, 3 feet.
SD 4	"Salpa" Dredge; width, 4 feet.
STL	Surface Seine Net, large.
TD 3	Triangular Dredge; each side 3 feet.
TD 4	Triangular Dredge; each side 4 feet.

Times are expressed on the 24-hour system. The entry under "from" gives the time when all the wire had been paid out and towing actually commenced; that under "to" gives the time when hauling actually commenced, or when, in the case of the net being closed by the self-closing mechanism, it was estimated that the "messenger" had arrived.

In all cases the tow-nets were shot open; they were then towed more or less horizontally during the time indicated in the two columns and, except in those cases where it is stated that they were closed by means of the self-closing mechanism, were hauled, at the time given in the column "to", obliquely to the surface, fishing all the time. The actual depths at which the nets are presumed to have fished are indicated by the figure given in the appropriate column followed by the expression "–0". Where a depth-recorder was used this fact is indicated by an asterisk in the "Remarks" column, following the statement of the length of wire out after the deepest net, as for example:

"N 200 2000–0, ... , 14.21, 2265 m. of wire out.*"

Summary of Stations by Cruises.

Cruise	1.	Red Sea to Aden	Stations A, 1–18, M.B. I.
,,	2.	Aden to Aden	,, 19–37.
,,	3.	Aden to Karachi	,, 38–61, M.B. II.
,,	4.	Karachi to Bombay	,, 62–90.
,,	5.	Bombay to Mombasa	,, 91–102.
,,	6.	Mombasa to Zanzibar	,, 103–126.
,,	7.	Zanzibar to Colombo	,, 127–135.
,,	8.	Colombo to Colombo	,, 136–165.
,,	9.	Colombo to Aden	,, 166–196.
,,	10.	Aden to Red Sea	,, 197–209.

Summary of Stations by Areas.

Red Sea	Stations A, 1–11, 203–209, and M.B. I.
Gulf of Aden	,, 12–21, 23–39, and 174–202.
South Arabian Coast	,, 40–59, 77–80, and M.B. II.
Gulf of Oman	,, 64–76.
Northern area of Arabian Sea	,, 60–63, 81–90.
Central part of Arabian Sea	,, 22, 91–102, and 166–173.
Zanzibar area	,, 103–126.
Southern area of Arabian Sea	,, 127–135.
Maldive area	,, 136–165.

Station Li

Station.	Position. N. °	′	″	E. °	′	″	Date.	Hour.	Sounding (metres).	Wind. Direction.	Wind. Force.	Sea. Direction.	Sea. Force.	Weather.	Barometer. ″	Air temp. (° Cent.).	Re
							1933.										
A.	29	17	00	32	43	00	6.ix	11.45	65–68	N	4	N	3	b. ○	29·81	29·4	
1	25	24	30	36	12	12	10.ix	13.20	2204	NW	3–4	NW	4	b. c. ◐	29·7	33·33	
2	23	12	18	37	26	18	11.ix	11.30	1008	NW×N	4	NW×N	4	b. ○	29·7	30·11	
3	20	46	12	38	12	42	12.ix	7.0	2094	NW×N	3	NW×N	3	b. c. ◍	29·74	30·28	
4	20	43	48	38	15	18	12.ix	13.28	2001	NW	3	NW	3	b. c. ◍	29·68	31·11	
5	18	59	00	39	13	30 to	13.ix	14.15	938	NNW	4	NNW	4	b. c.	29·70	31·11	
	18	49	18	38	23	42											
6	17	06	18	40	37	24 to	14.ix	8.30	1167	N × W	3–4	N × W	3	b. c.	29·73	33·89	
	17	03	18	40	40	06											
7	13	58	48	42	22	42	16.ix	8.20	260	NNW	2	NNW	2	b. ○	29·72	33·33	
8	13	41	00	42	31	30	16.ix	14.0	101	NW	3	NW	3	b. ○	29·69	33·33	
9	13	35	30	42	35	05	17.ix	9.30	245	NNW	3	NNW	3	b. ○	29·72	32·78	
10	13	31	00	42	31	00	17.ix	15.0	55	NW×N	3–4	NW×N	3	b. ○	29·60	32·78	
11	12	55	42	43	11	42 to	18.ix	12.07	207	NW	3	NW	3	b. ○	29·69	32·78	
	12	53	36	43	11	18											
12	12	23	12	43	54	48	19.ix	9.43	483	NW	2	NW	2	b. ○	29·68	28·89	
13	12	12	30	43	45	30	19.ix	14.20	413	NNW	3–4	NNW	3	b. ○	29·60	28·89	
14	11	56	00	43	38	30	19.ix	18.45	1764	NE	5	NE	5	b. c.	29·62	30·00	
15	10	56	00	44	29	42	20.ix	9.0	1053	NW	3	NW	3	b. ○	29·69	32·22	
16	10	29	48	45	01	48	21.ix	8.0	186	SW	3	SW	3	b. ○	29·70	31·67	
17	10	36	12	45	03	48	21.ix	11.30	854	WSW	3	WSW	3	b. ○	29·70	32·78	
18	10	54	30	45	05	48 to	21.ix	17.15	1375	N	2	N	1	b. ○	29·68	30·56	
	10	54	30	45	10	48											
19	12	31	00	45	20	48 to	28.ix	10.15	1118	ESE	3	ESE	3	b. ○	29·78	31·11	
	12	27	00	45	20	12											
20	11	54	12	45	16	30 to	28.ix	18.10	1132	ENE	1	ENE	1	b. c. ◐	29·76	30·00	
	11	52	54	45	15	06											
21	11	18	36	45	05	18 to	29.ix	6.10	1518	ESE	3	ESE	3	b. ○	29·82	30·56	
	11	17	54	45	04	12											
22	10	56	36	52	20	12	5.x	15.0	3556	S	4	S	3	b. c. ◐	29·82	22·22	Mod.
23	12	04	00	51	39	42	9.x	6.10	949	SSE	3	SSE	2	b. ○	29·84	22·78	Slight

Stations of H.E.M.S. "Mabahiss".

Hydrological observations.						Transparency of the water (SD reading).		Nature of bottom.	Biological observations.				Remarks.
Surface.			Sub-surface.						Gear.	Depth (metres).	Time.		
Depth (metres).	Temp. (° Cent.).	S. ‰.	Depth (metres).	Temp. (° Cent.).	S. ‰.	Depth (metres).	Time.				From	To	
0	24·7	..	62	21·07	..	..	..	sft. y. m.	OT	65–68	..	..	..
0	28·90	40·70	1900	21·84	40·97	33·0	17.45	..	..	..	..	..	..
..	..	..	..	..	..	..	..	..	..	..	..	..	Bigelow tube lost.
0	33·0	39·09	..	..	..	..	..	sft. y. m.	AT	2176	9.18	10.35	Trawl lost.
0	31·20	39·20	1900	21·81	40·53	32·0	17.05	..	..	..	..	..	..
0	31·1	39·09	..	..	..	..	..	sft. y. m.	TD 3 N 200	938 500–0	11.50 17.23	12.0 17.55	Marking trawl wire. 900 m. of wire out.
0	31·64	38·98	1000	21·64	40·57	..	..	r. sh.	SD 4	1167	13.53	14.25	..
0	32·12	38·22	250	21·89	40·48	23·5	10.30	c. blk. s.; sh.	N 200 DC	100–0 260	10.35 11.35	11.05 11.40	220 m. of wire out. Rope strop carried away.
0	32·13	38·03	100	17·20	36·38	24·0	15.30	..	..	..	..	..	..
0	31·79	38·13	245	21·69	39·60	..	..	r. s.	TD 4	245	12.15	12.45	Net torn.
0	31·2	38·31	..	..	..	..	..	..	OT	55	15.0	15.45	..
0	33·32	38·17	..	..	..	..	..	r.	TD 3	207	12.45	13.15	Rope strop parted. Net badly torn.
0	23·46	36·00	450	17·15	36·94	3·5	12.0	c. s. sh.	..	..	..	..	..
0	28·27	37·32	350	14·39	35·88	8·5	16.15	..	..	..	..	..	..
0	30·21	37·70	1000	17·35	37·79	..	..	br. m.	..	..	..	..	..
0	30·6	36·42	..	..	..	..	..	gr. br. m.	AT	1053	11.20	12.25	Trawl fouled and did not fish.
0	29·4	37·34	..	..	..	..	..	sft. br. m.	AT	186	8.50	9.42	..
0	30·27	37·36	800	15·84	37·00	13·5	13.45	br. m. s.	..	..	..	..	..
..	..	..	..	..	..	..	..	br. m.	N 200	900–0	17.40	18.05	1500 m. of wire out.
0	30·38	36·65	1000	9·81	35·73	23·0	13.0	..	..	..	..	..	..
0	30·19	36·58	1000	9·63	35·73	..	..	sft. br. m.	..	..	..	..	..
0	29·44	36·65	1400	6·35	35·17	13·5	8.35	gn. m.	..	..	..	..	..
0	22·77	35·32	1965	3·01	34·72	..	..	lt. gy. m.	..	..	..	..	..
0	23·20	35·36	723	9·77	35·35	20·0	8.30	..	..	..	..	..	..

Station List I.—

Station.	Position. N.	Position. E.	Date.	Hour.	Sounding (metres).	Wind. Direction.	Wind. Force.	Sea. Direction.	Sea. Force.	Weather.	Barometer.	Air temp. (° Cent.).	Remarks.
	° ′ ″	° ′ ″	1933.								″		
24	11 53 42	51 13 12	9.x	13.0	73–220	SE	3	S	2	b. ○	29·76	27·22	S. swell
25	12 13 42	50 54 18	10.x	10.30	620	NW	1	..	..	b. ○	29·78	27·78	Confused S. swell
26	12 29 30	50 51 30	11.x	5.0	2312	E	3–4	E	3	b. ○	29·88	25·55	..
27	11 57 12	50 35 00 to	12.x	7.15	37	N	3	N	2	b. ○	29·84	26·11	..
	11 56 42	50 39 12											
28	12 00 00	50 38 42	12.x	12.20	201	ENE	3	ENE	2	b. ○	29·81	27·78	..
29	12 13 36	50 40 30	12.x	15.30	2072	ENE	2–3	ENE	2	b. ○	29·76	30·00	..
30	12 36 54	51 19 48	13.x	5.30	1602		Dead	calm		b. ○	29·83	27·78	..
31	13 25 36	51 07 00 to	13.x	15.15	1982		Dead	calm		b. ○	29·79	28·33	..
	13 32 54	51 09 24											
32	14 40 42	50 54 48 to	14.x	9.0	1178	E	3	E	3	b. ○	29·90	26·67	..
	14 40 12	50 50 42											
33	13 41 00	48 17 00 to	15.x	11.30	1295	E	4	E	3	b. ○	29·79	26·67	..
	13 40 00	48 19 00											
34	13 05 36	46 24 42	16.x	8.30	1022	NW	0–2	..	..	b. ○	29·74	30·00	Slight SE swell
35	13 14 24	46 14 12 to	16.x	16.0	441	SSE	1–2	Smooth		b. ○	29·74	30·00	..
	13 13 24	46 10 00											
36	12 38 00	45 11 00	17.x	5.30	395	W	2	W	2	b. z. ○	29·80	26·11	..
37	12 47 30	45 04 30 to	17.x	11.0	18	S	3	S	3	b ○	29·81	29·44	..
	12 50 00	45 05 00											
38	14 03 06	51 00 00 to	24.x	8.50	2458	E × S	2–3	E × S	2	b. ○	30·00	25·5	Slight SE swell
	14 05 48	51 00 24											
39	13 53 30	52 53 42 to	25.x	6.30	2156	ENE	4	ENE	3	b. ○	30·06	25·56	Slight S. swell
	13 51 54	52 44 54											
40	15 41 30	55 41 06 to	26.x	16.0	2897	NE	1	Smooth		b. ○	29·90	26·11	V. slight S or ESE swell
	15 43 18	55 40 36											
41	17 11 12	55 50 30 to	27.x	6.0	2970	SSW	1	Smooth		b. ○	30·00	28·89	Slight WSW swell
	17 09 00	55 44 30											
42	17 26 00	55 49 00	27.x	12.50	1415	SE	1–2	Smooth		b. c. ◐	29·97	27·22	Slight WSW swell
43	17 29 00	55 47 00	28.x	10.0	95	NNE	2	Smooth		b. c. ◐	30·02	27·22	..
44	17 45 00	56 13 00	29.x	9.40	55	ENE	2	Smooth		b. c. ◐	30·02	26·67	Slight S swell
45	18 03 30	57 02 30	29.x	17.20	38	E × N	1	Smooth		b. c. ◐	29·80	26·11	Slight S swell
46	18 34 00	58 14 42	30.x	6.30	2912	SSW	2	SSW	2	b. c. ◐	29·98	28·33	Slight ESE swell
47	18 50 12	57 48 54	30.x	12.0	104	NW	3	NW	2	b. c. ◐	29·98	26·67	Slight ESE swell
48	18 49 00	57 51 00	30.x	14.10	201	NNE	3	Smooth		b. ○	29·90	26·67	Slight ESE swell

Stations of H.E.M.S. "Mabahiss".

Hydrological observations.						Transparency of the water (SD reading).		Nature of bottom.	Biological observations.				Remarks.
Surface.			Sub-surface.						Gear.	Depth (metres).	Time.		
Depth (metres).	Temp. (° Cent.).	S. °/₀₀.	Depth (metres).	Temp. (° Cent.).	S. °/₀₀.	Depth (metres).	Time.				From	To	
0	29·7	36·18	..	..	..	..	..	c. s. sh. (? r.)	DC	73–200	13.25	13.35	..
									OT	73–200	14.47	15.47	Net badly torn.
0	29·92	36·27	500	13·54	35·97	18·0	16.20	sft. gy. m. (? r.)	AT (i)	620	11.45	12.45	Cod-end badly tied.
									(ii)	620	16.35	..	Trawl lost.
0	28·7	36·22	2290	2·74	34·76	..	..	sft. gy. w. m.	AT	2312	10.25	11.25	..
0	29·5	36·74	..	..	..	..	..	s. sh.	OT	37–91	7.30	9.30	..
0	29·7	36·71	..	..	..	..	..	c. gr. s. m. sh.	G	..	..	..	..
0	28·9	36·02	..	..	..	..	..	gn. m.	AT	..	..	..	Net fouled ; did not fish.
0	25·41	35·43	1377	5·86	35·07	17·0	9.30	..	..	..	..	..	..
0	26·68	35·99	1500(?)	5·58	35·36	9·0	17.55	..	..	..	..	..	..
0	26·95	35·96	900	10·29	35·71	..	..	gn. m. s. sh.	..	..	..	..	..
0	27·80	36·73	1280	7·16	..	..	..	gr. m.	AT	1295	14.25	16.15	..
0	30·30	37·00	1000	10·21	..	..	..	gn. m.	AT	1022	11.15	12.46	..
0	30·00	36·98	440	12·65	35·56	..	..	gn. m. s. sh.	OT	457–549	17.40	18.30	..
0	29·51	..	400	13·53	35·79	27·0	7.05	gn. m.	..	..	..	..	..
0	30·30	36·49	..	..	..	..	..	s.	OT	18–22	11.18	13.18	..
0	27·32	36·38	2000	3·61	34·83	16·5	12.0	lt. gn. m.	..	..	..	..	..
0	26·60	35·82	2000	3·45	..	15·0	9.50	lt. gn. m.	..	..	..	..	..
0	27·86	35·95	2000	3·14	..	15·0	16.30	..	..	..	..	..	..
0	26·54	35·82	2500	2·31	34·96	20·0	8.35	..	..	..	..	..	..
0	27·7	36·30	1316	6·74	35·10	..	..	r. m.	TD 4	1415	14.55	15.35	Net torn.
0	27·10	36·17	100	18·94	35·61	21·0	11.15	..	OT	83–100	12.0	14.0	..
..	..	..	..	..	..	..	..	..	STL	0	9.40	11.10	Experimental.
0	26·83	36·04	35	20·37	35·73	..	..	Lith.	TD 4	38	18.31	19.16	..
0	27·69	36·56	2500	2·11	34·87	23·0	9.05	..	..	..	..	..	..
0	28·00	36·33	100	19·63	35·79	28·0	12.23	c. s. sh.	..	..	..	..	..
..	..	..	..	..	..	..	..	? r.	AT	201–274	14.35	15.05	Net badly torn.

Station List I.—

Station.	Position. N. °	′	″	E. °	′	″	Date.	Hour.	Sounding (metres).	Wind. Direction.	Wind. Force.	Sea. Direction.	Sea. Force.	Weather.	Barometer.	Air temp. (° Cent.).	Remarks.
							1933.								″		
49	18	45	00	57	53	00	31.x	7.20	975	ESE	2	Smooth		b. ○	29·98	26·67	Slight ESE swell
50	18	38	00	58	05	00	31.x	10.35	1939	ESE	2	Smooth		b. c. ◐	29·96	26·67	Slight ESE swell
51	18	56	30	58	07	00	1.xi	9.30	832	NW	3	NW	3	b. c. ◐	30·02	25·56	Slight ESE swell
52	19	00	54	58	01	12	1.xi	12.10	105	NW	3	NW	3	b. c. ◐	30·02	26·1	Slight ESE swell
53	19	22	36	57	53	00	2.xi	9.05	13·5	NNE	3	Smooth		b. ○	29·96	26·67	Slight ESE swell
54	21	50	00	59	52	00	3.xi	12.15	1046	NNW	2	NNW	2	b. ○	29·91	27·2	..
55	22	07	30	59	52	12	4.xi	8.40	794	NNE	1–2	Smooth		b. ○	29·89	26·11	..
56	22	12	42	59	51	18	4.xi	13.33	421	NNW	1	Smooth		b. ○	29·86	27·22	..
57A	22	23	00	59	54	12	5.xi	8.10	703	NE	2–3	NE	3	b. ○	29·93	26·11	..
57B	22	22	54	59	55	18	5.xi	9.42	703	NE	2–3	NE	3	b. ○	..	..	..
58	22	22	12	59	57	30	5.xi	11.35	1205	SW	2	SW	2	b. ○	29·82	26·11	..
59	22	22	48	60	06	24 to	6.xi	6.0	1948	ENE	2	Smooth		b. c. ◐	30·02	26·11	..
	22	25	24	60	10	00											
60	21	58	00	62	19	42 to	7.xi	6.30	3054	N	3	N	3	b. c. ◐	30·03	26·11	..
	21	58	36	62	21	24											
61 A⎫	23	02	48	64	31	54 to	8.xi	6.0	2290	NNE	2	NNE	3	b. ○	30·05	26·11	Slight W. swell
61 B⎭	23	02	30	64	41	00	8.xi	15.42	2160	..	..	..	..		..	..	..
61 C⎫	23	02	12	64	33	39 to	8.xi	18.00	2317	NNW	3	NNW	3	b. ○	29·97	25·0	..
61 D⎭	23	02	30	64	15	54	9.xi	4.12	2487	NNW	3	NNW	3	b. ○	..	..	..
62	22	53	30	64	56	10 to	18.xi	7.30	1893	NE	4	NE	4	b. c. ◐	29·92	27·50	..
	22	56	30	64	56	30											
63	24	37	18	63	07	36 to	19.xi	8.30	1703	NW	3	NW	3	b. c. ◐	29·99	25·0	Slight NE swell
	24	37	42	63	06	24											

Stations of H.E.M.S. "Mabahiss".

Hydrological observations.						Transparency of the water (SD reading).		Nature of bottom.	Biological observations.				Remarks.
Surface.			Sub-surface.						Gear.	Depth (metres).	Time.		
Depth (metres).	Temp. (° Cent.).	S. °/₀₀.	Depth (metres).	Temp. (° Cent.).	S. °/₀₀.	Depth (metres).	Time.				From	To	
0	27·26	36·35	800	10·76	35·57	25·0	8.50	..	..	..	..	..	..
0	27·94	36·53	1500	5·55	35·10	26·5	10.35	br. m.	TD 4	1536–1939	15.30	16.16	Rope strop carried away.
0	27·64	36·51	800	10·35	35·50	30·0	10.55	..	..	..	..	..	..
0	27·35	36·33	100	19·09	35·83	19·5	12.10	c. s.	..	..	..	..	..
..	..	..	10·5	22·79	35·83	..	..	r. sg. sh. lith.	TD 4	13·5	9.32	9.49	Rope strop carried away.
0	26·9	36·09	900	9·59	35·56	..	..	gn. m.	AT	1046	14.26	15.30	Net torn.
0	26·9	36·36	800	10·13	35·64	..	..	br. gn. m. s. over gy. gn. m.	SD 4	794–802	10.30	11.10	Rope strop carried away. Net torn.
..	..	..	..	..	..	..	..	gn. m.	TD 4	421	14.09	14.25	H_2S present.
0	27·2	36·92	750	10·63	35·52	..	..	sft. gn. m. st.	..	..	..	..	Bottom very irregular; H_2S present.
..	..	..	..	..	..	..	..	..	TD 4	428–606	10.0	10.32	Rope strop carried away.
0	26·7	36·55	1240	6·95	35·14	..	..	gn. m.	TD 4	1189–1354	14.11	15.02	Bottom very irregular: H_2S present.
0	26·9	36·64	1910	3·16	34·76	..	..	sft. gn. m.	TD 4	1948	9.18	10.15	..
0	27·20	36·22	..	..	..	..	..	gl. oz.	..	..	..	..	..
0	27·86	36·355	400	14·10	35·71	28·0	9.55	..	NS 50	0	13.25		..
			600	12·07	35·34				N 100	500–0			570 m. of wire out.
			1000	9·00	35·16				N 100	1000–0			1136 m. of wire out.
			1500	5·57	34·92				N 100	1500–0			1702 m. of wire out.
			2000	3·18	34·605				N 200	2000–0		14.21	2265 m. of wire out.*
0	27·83	36·27	400	13·80	35·53	..	..	..	NS 50	0	1.26		..
			600	11·89	35·39				N 100	500–0			570 m. of wire out. Net carried away.
									N 100	1000–0			1136 m. of wire out.
									N 100	1500–0			1702 m. of wire out.
									N 200	2000–0		2.32	2265 m. of wire out.*
0	26·22	36·33	1890	4·03	35·46	..	..	gy. cl.	AT	1893	10.42	11.42	..
0	25·7	36·67	1690	8·58	35·36	..	..	gy. cl.	AT	1703	11.45	12.45	Net carried away.

STATION LIST I.—

Station.	Position. N.	Position. E.	Date.	Hour.	Sounding (metres).	Wind. Direction.	Wind. Force.	Sea. Direction.	Sea. Force.	Weather.	Barometer.	Air temp. (° Cent.).	Remarks.
	° ′ ″	° ′ ″	1933.								″		
64	24 47 00 24 46 54	61 21 18 to 61 17 48	20.xi	8.30	448	NE	5	NE	5	b. ○	30·07	26·4	..
65	25 02 12	59 40 30	21.xi	9.10	907	SE	3	SE	3	b. c. ⦶	30·08	26·67	..
66	23 44 24	58 40 00	22.xi	6.30	609	W	1	W	1	b. c. ⦶	30·02	26·11	..
67	23 41 48	58 36 00	22.xi	13.27	274	Dead calm				b. c. ⦶	30·01	32·22	..
68	24 39 48 24 42 12	59 21 54 to 59 25 00	24.xi	7.0	1745	SE	3	SE	3	b. c. ◍	29·98	25·6	Slight S. swell
69	25 12 12 25 10 12	57 16 36 to 57 13 12	25.xi	8.15	1257	NE	2–3	NE	3	b. c. ⦶	30·00	24·33	..
70	25 34 12 25 33 00	57 23 30 to 57 25 12	25.xi	13.55	196	NE	1	Smooth		b. c. ⦶	29·94	24·67	..
71	25 35 00 25 43 00	56 42 18 to 56 39 18	26.xi	9.30	106	WSW	3	WSW	3	b. c. ◍	30·01	25·28	..
72	25 38 18	56 26 36	26.xi	13.32	73	W	3	W	3	b. c. ⦶	29·94	25·00	..
73	25 28 48	56 35 54	27.xi	8.57	91	SE	3	SE	3	b. c. ◍	30·00	23·3	..
74	25 17 00	56 45 00	27.xi	14.17	155	NW	2–3	Smooth		o. ◍	30·00	25·56	..
75	25 10 48 25 09 48	56 47 30 to 56 47 30	28.xi	9.30	201	SE	2	SE	2	b. c. ⦶	30·05	26·11	..
76A	24 10 36	59 00 36	29.xi	8.0	3289	ESE	3–4	ESE	4	b. c. ⦶	30·06	24·9	..
76B	24 13 54 24 16 42	59 03 30 to 59 06 06	29.xi	14.17	..	ESE	3	ESE	3	b. c. ⦶	..	..	..
77	22 13 30	59 52 00	30.xi	12.0	421	ESE	3	ESE	3	b. c. ⦶	30·05	25·3	..
78	22 13 36	59 50 48	30.xi	14.40	150	ESE	3	ESE	3	b. c. ⦶	..	..	..
79	22 12 48	59 49 42	30.xi	14.55	102	ESE	3	ESE	3	b. c. ⦶	29·98	25·56	..
80	22 13 30	59 48 48	30.xi	16.40	16–22	ESE	3	ESE	3	b. c. ⦶	..	..	..
81	23 17 06 23 18 24	61 00 36 to 61 10 12	1.xii	7.45	3351	ENE	2	ENE	2	b. c. ◍	30·02	24·7	Mod. ENE swell
82	20 41 00 20 41 18	61 18 12 to 61 16 36	3.xii	4.30	3413	W × S	2	W × S	3	b. ○	29·96	25·0	Slight ESE swell
83	20 09 06 20 10 06	64 32 36 to 64 30 24	4.xii	6.30	3235	NNE	3	NNE	4	b. c. ◍	29·99	..	Mod. NNW swell
84	19 29 30 19 29 48	68 56 00 to 68 54 18	5.xii	15.30	2392	NNE	3	NNE	3	b. c. ⦶	29·92	26·67	Slight N swell

Stations of H.E.M.S. "Mabahiss".

Hydrological observations.						Transparency of the water (SD reading).		Nature of bottom.	Biological observations.				Remarks.
Surface.			Sub-surface.						Gear.	Depth (metres).	Time.		
Depth (metres).	Temp. (° Cent.).	S. ‰	Depth (metres).	Temp. (° Cent.).	S. ‰	Depth (metres).	Time.				From	To	
0	25·9	36·73	435	14·06	36·02	..	..	gy. cl.	MT	448	10.05	11.10	..
0	26·39	36·77	800	10·41	35·53	17·0	11.20	sft. gn. m.	TD 4	907	12.56	13.30	..
0	27·20	36·96	600	12·31	35·77	19·0	8.35	sft. br. gn. m.	TD 4	609	9.30	10.0	..
..	..	..	..	..	..	..	..	sft. gn. m. st.	TD 4	274	13.43	14.43	..
0	26·18	36·71	1500	5·36	35·07	22·5	10.22	sft. gn. m.	TD 4	1491–1518	11.40	12.45	..
0	26·80	36·78	1000	8·62	35·35	20·0	10.30	..	..	..	..	..	..
0	26·35	36·78	195	19·32	36·04	..	..	sft. gn. m.	OT	196	15.05	16.05	..
0	26·00	37·01	100	25·04	38·58	13·5	10.05	c. s. m.	OT	106	10.40	11.43	..
0	26·2	36·94	..	..	..	..	..	c. s. sh.	AT	73	14.10	15.10	..
..	..	..	..	..	..	..	..	gn. m. s. sh.	G	91	..	..	..
..	..	..	160	20·59	37·19	..	..	gn. m. s. pt.	G	155	..	..	..
..	..	..	..	..	..	..	..	gn. m.	G	201	..	..	..
0	26·71	36·96	..	..	..	19·0	10.55	gy. m.	NS 50	0–1	15.30		Net split.
			200	17·48	36·24				N 100	200			300 m. of wire out.
			600	12·38	35·84				N 100	600			800 m. of wire out.
			1500	5·75	35·075				N 100	1500			1800 m. of wire out.
			2500	2·27	34·78				NS 50 N 200	2500		16.30	Net split. 2800 m. of wire out.
0	26·7	36·60	..	..	..	..	..	gr. m.	G	411	..	..	H_2S present.
									SD 4	370	13.27	14.07	Bottom shoaling.
..	..	..	..	..	..	..	..	gr. m.	BR	150	..	..	H_2S present.
0	26·5	36·58	..	..	..	..	..	gr. m.	SD 4	95–102	15.27	15.57	H_2S present.
..	..	..	..	..	..	..	..	c. s. sh.	SD 4	16–22	16.54	17.26	..
0	26·39	36·87	3000	1·90	34·78	17·0	12.05	gy. cl.	MT	3351	15.55	16.45	..
0	26·53	36·58	3000	1·86	34·73	30·0	7.10	..	..	..	..	..	..
0	26·47	36·47	3000	1·81	34·74	32·0	9.35	..	..	..	..	..	..
0	27·37	35·26	2000	3·11	34·83	..	..	..	..	..	..	..	..

Station List I.—

Station.	Position. N. °	′	″	E. °	′	″	Date.	Hour.	Sounding (metres).	Wind. Direction.	Wind. Force.	Sea. Direction.	Sea. Force.	Weather.	Barometer. ″	Air temp. (° Cent.).	Remarks.
							1933.										
85	19	24	54	69	18	48 to	6.xii	4.30	1687	N × E	3	N × E	3	b. c.	29·94	25·56	Slight N swell
	19	24	48	69	20	54								◔			
86	19	24	20	69	24	18 to	6.xii	10.55	1021	NNE	3–4	NNE	4	b. c.	29·98	26·67	Slight confused
	19	25	42	69	22	54								◔			swell
87	19	21	18	69	30	30 to	7.xii	5.50	582	NW	2	NW	3	b.	29·92	26·4	Slight confused
	19	19	00	69	30	24								○			swell
88	19	16	12	69	39	48	7.xii	10.10	274	NW	2	NW	3	b. c.	..	..	Slight confused
														◔			swell
89	19	14	00	69	42	18	7.xii	11.0	193	ENE	3	ENE	3	b. c.	29·97	26·56	Slight confused
														◔			swell
90	19	18	00	69	59	00	7.xii	15.50	91	ENE	3–4	ENE	4	b. c.	29·98	26·56	Slight confused
														◔			swell
91	17	42	30	71	12	54	14.xii	6.15	124	NE × N	4	NE	4	b.	29·96	27·50	Mod. confused
														○			swell
92	16	09	36	68	50	54 to	15.xii	6.0	3722	NE	3–4	NE	4	b. c.	29·90	26·56	Mod. NE swell
	16	05	36	68	49	24								◔			
93	14	24	24	66	12	42 to	16.xii	15.10	3991	NE × N	4	NE	4	b. c.	29·82	26·94	Mod. NE swell
	14	22	18	66	11	54								◑			
94	13	25	36	65	08	06 to	17.xii	8.0	4073	NE	3	NE	3	b. c.	29·92	26·39	Slight to mod.
	13	24	00	65	08	06								◔			NE swell
95	12	08	06	63	04	36 to	18.xii	5.30	4277	NE	3	NE	3	b. c.	29·96	26·11	Slight NE
	12	05	18	63	01	42								◑			swell
96	10	54	42	61	20	54 to	19.xii	8.30	4459	N	3	N	3	b. c.	29·96	26·11	Slight NNE
	10	53	18	61	22	24								◔			swell
97	10	56	18	59	55	24 to	21.xii	0.0	4230	NNE	3	NNE	3	b. c.	29·93	25·78	Slight NE
	9	52	12	59	51	30								◑			swell
98	6	58	42	55	41	00	22.xii	9.10	..	NNE	4	NNE	4	b. c.	29·93	26·11	NE swell
														◕			
99	6	10	30	54	52	12 to	23.xii	21.0	5106	NNE	3	NNE	3	b. c.	29·90	26·11	Slight NE
	6	09	42	54	51	00	24.xii	1.30						◕			swell
100	4	00	36	51	27	12 to	25.xii	9.0	5082	NE × N	3	NE × N	3	b. c.	29·90	26·11	..
	3	52	36	51	22	06								◑			
101	1	25	00	47	37	48 to	27.xii	8.30	4285	NE	2–3	NE	3	b. c.	29·92	25·56	Slight NE
	1	25	00	47	42	24								◑			swell
	S.			E.													
102	1	00	54	43	45	48 to	29.xii	8.30	3215	ENE	3	ENE	3	b. c.	29·90	26·67	Slight NE
	1	05	00	43	48	00								◑			swell
							1934										
103	5	39	30	39	11	30	11.i	9.15	101	NNE	4	NNE	4	b. c.	29·85	27·28	..
														◑			

Stations of H.E.M.S. "Mabahiss".

Hydrological observations.						Transparency of the water (SD reading).		Nature of bottom.	Biological observations.				Remarks.
Surface.			Sub-surface.						Gear.	Depth (metres).	Time.		
Depth (metres).	Temp. (° Cent.).	S. °/₀₀.	Depth (metres).	Temp. (° Cent.).	S. °/₀₀.	Depth (metres).	Time.				From	To	
0	27·10	35·21	1660	4·41	34·94	..	..	gy. cl.	MT	1519–1705	6.55	7.59	..
0	28·0	35·08	990	8·67	35·35	..	..	gn. m. s. sg.	AT	759–1024	12.25	14.30	Very foul ground.
0	26·7	35·81	579	11·80	35·57	..	..	bl. m. over gy. gr. m. s.	AT	549–640	7.30	8.30	..
..	..	..	..	..	..	..	..	br. m. over gy. cl.	G	274	..	..	..
0	27·22	35·59	178	20·44	35·50	..	..	s. sh. r.	G	193	..	..	..
									OT	135–183	12.45	13.32	Rope strop on nippers parted. Net torn; one otter board damaged.
0	26·9	35·70	..	..	..	..	..	s. sh. cr.	G	91	..	..	..
0	27·03	35·30	100	21·69	35·23	24·5	7.50	..	..	..	..	..	..
0	27·10	36·06	3500	1·75	..	30·0	10.20	gl. oz.	AT	3722	12.15	14.15	Wire parted. Trawl lost.
0	26·89	36·31	4000	1·64	34·76	24·5	15.20	cm. m. over gy. oz.	..	..	..	..	..
0	26·56	36·58	..	..	..	..	..	..	N 200	984–1045	9.16	10.16	Self-closing mechanism used. 1400 m. of wire out.*
0	26.05	36·31	400	12·12	35·46	22·0	9.37	..	N 200	430–984	14.19	15.49	1400 m. of wire out.*
			600	10·64	35·39								
			800	9·58	35·32								
			1000	8·48	35·25								
			4000	1·72	34·70								
..	..	..	..	..	..	..	..	..	N 100	10	9.10	..	15 m. of wire out.
									N 100	390–635			890 m. of wire out.
									N 200	400–645		10.40	900 m. of wire out.*
0	26·69	36·11	3500	1·77	34·78	20·0	6.45	..	..	..	..	..	..
						20·0	12.0						
						17·0	17.10						
0	26·6	35·82	..	..	..	..	..	..	N 200	2800–0	11.09	12.14	2800 m. of wire out.*
0	26·39	35·88	3000	2·02	34·81	..	..	..	..	..	..	..	..
0	26·00	35·88	20	25·91	35·88	25·0	14.45	br. m. over gy. oz.	HN	25–15	..	..	..
			40	23·70	35·57					45–35			
			5000	1·23	24·72								
0	25·31	35·61	20	25·24	35·59	15·0	11.45	br. m. over gy. oz.	HN	20–0	11.50	..	..
			40	25·00	35·57					35–25			
			4200	1·41	34·72								
0	25·80	35·52	3000	1·77	34·69	15·0	12.15	br. m. over gy. oz.	..	..	..	..	..
..	..	..	..	..	..	..	..	c. s. sh.	G	101	..	..	..

Station List I.—

Station.	Position. S.	Position. E.	Date.	Hour.	Sounding (metres).	Wind. Direction.	Wind. Force.	Sea. Direction.	Sea. Force.	Weather.	Barometer.	Air temp. (° Cent.).	Remarks.
	° ′ ″	° ′ ″	1934.								″		
104	5 37 54	39 11 36	11.i	10.29	207	NNE	4	NNE	4	b. c. ◐	..	..	..
105A	5 36 12	39 13 12	11.i	11.20	280	NNE	4	NNE	4	b. c. ◐	..	..	..
105B	5 34 24 5 37 00	39 14 06 to 39 14 36	11.i	12.10	238	NNE	4	NNE	4	b. c. ◐	29·85	27·33	..
106	5 38 54 5 40 18	39 15 42 to 39 17 36	12.i	8.16	212	N × E	5	N × E	5	o. ◍	29·97	26·56	Mod. NE swell
107	5 15 30 5 17 14	39 33 00 to 39 32 48	12.i	15.20	439	NE	3–4	NE	3	b. c. ◐	29·72	28·6	..
108	5 18 06 5 14 30	39 24 12 to 39 25 36	13.i	8.25	781	NNW	4	NNW	4	b. c. ◍	29·90	25·72	..
109	5 10 36	39 33 48	13.i	13.20	640	NNE	4	NNE	4	b. c. ◐	29·71	26·94	..
110	5 03 42 5 05 48	39 15 24 to 39 15 12	14.i	11.16	329	NNE	3–4	NNE	3–4	b. c. ○	29·87	26·11	..
111	5 04 18	39 14 12	14.i	14.50	..	ESE	4	ESE	4	b. c. ○	29·77	27·22	..
112	5 04 57	39 13 18	15.i	7.20	113	N	4	N	4	b. c. ◐	29·92	25·0	..
113	5 05 17	39 13 39	15.i	7.40	220	N	4	N	4	b. c. ◐	..	..	..
114	5 06 08	39 14 05	15.i	8.48	353	N	4	N	4	b. c. ◐	..	..	..
115	5 05 18 5 01 00	39 22 12 to 39 24 12	15.i	10.30	640	NNE	4	NNE	4	b. c. ◐	29·88	27·22	..
116	3 27 24	40 08 24	16.i	8.30	256	NE	3–4	NE	4	o. ◍	29·95	25·56	Mod. NE swell
117	3 38 48 3 39 24	40 23 42 to 40 26 24	16.i	14.30	889	NE	4–5	NE	4	b. c. ○	29·80	27·22	..
118	4 05 54 4 17 00	41 10 12 to 41 11 48	17.i	7.15	1789	NE	5	NE	4	b. c. ◐	29·92	26·11	Mod. NE swell
119	6 29 24 6 32 00	39 49 54 to 39 53 30	19.i	10.15	1204	NNW	4	NNW	4	b. c. ◍	29·86	25·83	Mod. NE swell
120	5 49 12 5 52 24	41 28 12 to 41 40 12	20.i	9.0	2931	NE	5–6	NE	5	b. c. ○	29·87	26·11	Mod. NE swell
121	5 39 00 5 40 30	39 38 30 to 39 43 00	21.i	8.40	925	NNE	4	NNE	3	b. c. ◐	29·90	26·67	Mod. NE swell
122	5 21 24 5 22 36	39 23 00 to 39 22 18	22.i	9.10	745	NE × N	4	NE × N	4	b. c. ◐	29·90	23·89	Mod. NE swell
123	5 19 00 5 19 12	39 32 30 to 39 33 30	22.i	15.16	..	NE	3–4	NE	4	b. c. ○	29·74	25·00	Slight NE swell
124	5 39 00 5 39 12	39 39 24 to 39 42 12	23.i	8.20	914	NE	3	NE	3	b. c. ◐	29·90	26·11	Slight NE swell
125	5 36 12	39 28 24	23.i	14.12	805	NE	3	NE	3	b. c. ○	29·76	27·22	Slight NE swell

Stations of H.E.M.S. "Mabahiss".

Hydrological observations.						Transparency of the water (SD reading).		Nature of bottom.	Biological observations.				Remarks.
Surface.			Sub-surface.						Gear.	Depth (metres).	Time.		
Depth (metres).	Temp. (° Cent.).	S. ‰	Depth (metres).	Temp. (° Cent.).	S. ‰	Depth (metres).	Time.				From	To	
..	..	..	..	..	..	..	..	gr. gy. s. m. sh.	G	207	..	..	..
..	..	..	..	..	..	..	..	br. m. over. gn. m.	G	280	..	..	..
0	26·9	35·435	..	..	..	..	..	gn. m.	AT	238–293	12.42	13.44	..
0	26·5	35·24	212	15·52	35·21	..	..	gn. m.	AT	183–194	9.45	10.45	..
0	26·9	35·27	..	..	..	..	..	..	AT	421–457	15.50	16.38	Net caught on bottom; frame bent.
0	26·1	35·43	790	7·89	34·97	23·5	9.11	gy. m.	AT	786	10.03	11.04	Chain of foot rope parted.
..	..	..	627	8·86	34·84	..	..	lt. gy. m.	AT	640	14.04	15.11	..
0	26·5	35·43	320	12·85	35·14	..	..	gy. gr. m. s.	OT	347–384	12.48	13.35	..
..	..	..	..	..	..	..	..	? r.	AT	73–165	15.05	15.35	Rope strop on bridle parted; frame bent and net torn.
..	..	..	..	..	..	..	..	cr. r.	G	113	..	..	..
0	26·1	35·34	..	..	..	..	..	s. m. pt.	G	220	..	..	..
..	..	..	..	..	..	..	..	br. m. over gy. gr. m.	G	353	..	..	..
0	25·7	35·45	..	..	..	..	..	..	OT	640–658	11.40	13.40	..
0	25·13	35·22	240	13·88	35·14	10·5	12.09	gr. s.	..	..	..	..	..
0	26·00	35·30	890	7·53	34·81	22·5	14.45	gy. m.	..	..	..	..	..
0	26·81	35·37	1780	3·04	34·76	26·0	7.30	gl. oz.	AT	1789	12.30	14.07	..
0	26·22	35·43	1215	6·18	34·79	..	..	..	AT	1207–1463	12.50	14.00	..
0	26·89	35·42	2886	2·17	..	32·0	12.06	br. m. over gy. gl. oz.	AT	2926	14.10	15.15	..
0	26·5	35·37	907	6·94	35·05	..	..	gy. gr. m. s.	AT	?	10.21	11.51	Net apparently not on bottom.
0	26·5	35·35	748	8·31	34·88	..	..	gy. gr. m.	OT	732	10.50	11.58	..
0	26·7	35·41	..	..	..	..	..	gn. m. s. r.	TD 4	256–366	15.50	16.27	Frame broken and one chain gone. Net torn.
0	27·2	35·42	..	..	..	..	..	..	MT	914	9·28	10.35	Repeat of Sta. 121.
..	..	..	..	..	..	..	..	lt. br. m. over gy. cl.	G	805	..	..	..

Station.	Position. S.	Position. E.	Date.	Hour.	Sounding (metres).	Wind. Direction.	Wind. Force.	Sea. Direction.	Sea. Force.	Weather.	Barometer.	Air temp. (° Cent.).	Remarks.
	° ′ ″	° ′ ″	1934.								″		
126	5 38 42	39 17 42	24.i	9.30	209	NNE	3	NNE	3	b. c. ◐	29·90	26·11	..
127	7 32 24	44 09 30 to	1.ii	7.15	4091	N × W	3	N × W	3	b. c.	29·90	27·00	Mod. N swell
	7 34 12	44 05 12								◐			
128	5 31 42	49 33 30 to	3.ii	11.0	4060	N	3	N	3	b. c.	29·94	27·00	Slight NNE
	5 30 00	49 38 18								◐			swell
129	3 42 12	54 20 18 to	5.ii	7.15	2553	NE	3	NE	3	b. c.	29·91	26·89	Slight NE
	3 48 48	54 16 24								◐			swell
130	3 17 48	58 19 36 to	9.ii	9.05	4332	NE	1–2	NE	2	b. c.	29·92	27·00	Slight NE
	3 19 42	58 23 12								○			swell
131A	1 39 06	61 13 48 to	10.ii	17.30	4622	W	3	W	3	b. c.	29·92	27·50	Slight NE
	2 07 30	61 21 12								◐			swell
131D	1 39 06	61 13 48 to	11.ii	5.45	..	W × N	3	W × N	3	b.	..	..	Slight NE
	2 07 30	61 21 12								○			swell.
	N.	E.											
132	1 01 24	66 23 06 to	14.ii	6.0	4082	N × W	3	N × W	3	b. c.	29·91	27·67	Slight N
	1 02 54	66 10 18								◐			swell
133	1 25 54	66 34 12 to	15.ii	9.0	3385	NW	3	NW	3	b. c.	29·88	27·72	Slight NW
	1 19 42	66 35 18								◐			swell
134	2 55 30	70 05 30 to	17.ii	9.30	4234	NE	3	NE	3	b. c.	29·84	27·06	Slight confused
	2 49 54	69 51 18								○			swell
135	4 37 42	72 35 36 to	18.ii	20.45	2727	N	3	N	3	b. c.	29·82	27·06	..
	4 29 18	72 23 54								○			
	S.	E.											
136	3 06 18	73 29 42 to	21.iii	7.0	3628	WNW	3	WNW	3	b. c.	29·90	27·56	Slight W swell
	3 08 18	73 25 12								◐			

Stations of H.E.M.S. "Mabahiss".

Hydrological observations.						Transparency of the water (SD reading).		Nature of bottom.	Biological observations.				Remarks.
Surface.			Sub-surface.						Gear.	Depth (metres).	Time.		
Depth (metres).	Temp. (° Cent.).	S. ‰.	Depth (metres).	Temp (° Cent.).	S. ‰.	Depth (metres).	Time.				From	To	
..	..	..	..	..	..	..	..	lt. br. m. sh.	G	209	..	..	..
0	27·59	35·07	3225	2·22	34·69	34·5	13.15	y. over gr. gl. oz.	..	..	..	..	..
0	28·01	36·82	3235	1·73	34·76	37·0	15.0	cr. oz.	..	..	..	..	..
0	27·75	35·70	20	27·72	35·54	30·0	10.35	..	HN	20–0	11.30		..
			40	27·70	35·57					40–20			
			60	26·29	35·48					60–40			
			80	18·51	35·17					80–60			
			100	16·80	35·17					100–80			
			150	14·61	35·12					120–100		12.30	
			2000	6·41	34·81								
0	27·61	35·50	20	27·14	35·39	34·0	12.45	cr. oz.	HN	20–0	12.50		..
			30	27·11	35·39					50–30			
			50	26·05	35·39					80–60			
			60	22·60	35·30					110–90			
			80	19·12	35·21					150–130			
			100	18·35	35·21					200–160		14.0	
			150	15·88	35·16								
			200	14·61	35·12								
			4000	1·50	34·65								
0	27·92	35·54	..	..	..	..	..	..	N 200	600–0	1.50	2.15 (11th)	Vertical haul.
0	27·76	35·52	..	..	..	34·5	11.0	..	N 100	500–0	3.21		Vertical haul.
									N 100	1500–0			
									N 200	2500–0		4.40	
0	27·68	35·03	30	27·21	35·16	42·0	9.21	cr. oz. over gy. oz.	HN	35–0	10.30		..
			60	25·19	35·24					65–35			
			100	20·35	35·10					140–100			
			150	15·93	35·05					190–150		11.55	
			200	13·49	35·05								
			3500	1·58	34·61								
0	27·82	35·23	3000	1·92	34·78	38·0	11.40	r.	MT	3385	16.36	17.38	..
0	27·62	34·60	40	27·70	35·25	32·0	13.36	rd. cl.	HN	40–0	14.15		..
			80	26·30	35·30					80–40			
			100	25·21	35·43					120–80			
			150	15·32	35·40					160–120			
			200	13·68	35·10					200–160			
			300	11·90	35·07					240–200		15.55	
			3500	1·66	34·70								
0	27·30	34·46	2375	2·31	34·64	..	..	y. oz. over gy. gl. oz.	MT	2727	4.40	5.32	..
0	28·31	35·14	40	28·03	35·23	37·5	11.0	Hard	HN	40–0	12.20		..
			80	27·05	35·14					80–40			
			100	25·25	35·21					120–80			
			150	16·41	35·14					160–120		15.00	
			3500	1·65	34·74								

Station List I.—

Station.	Position. S.	Position. E.	Date.	Hour.	Sounding (metres).	Wind. Direction.	Wind. Force.	Sea. Direction.	Sea. Force.	Weather.	Barometer.	Air temp. (° Cent.).	Remarks.
	° ′ ″	° ′ ″	1934.								″		
137	0 36 00	73 12 48	23.iii	10.25	46	SW	3	..	..	b. ○	29·79	28·06	..
	(Anchorage, Addu Atoll.)												
	N.	E.											
138	2 12 00 2 10 00	73 16 48 to 73 14 48	25.iii	8.30	1900	NW	3	NW	3	b. c. ◍	29·97	26·78	..
139	2 13 30 (Anchorage, E side, Kolumadulu Atoll.)	73 09 00	25.iii	16.38	57	NW	3	..	..	o. p. ◍	29·88	27·00	..
140	2 39 54 2 41 42	73 22 12 to 73 18 48	26.iii	11.0	519	WNW	2	WNW	2	b. c. ◍	29·84	28·39	..
141	3 04 30 (Anchorage, W side, Mulakadu Atoll.)	73 22 42	26.iii	17.47	44	NW	3	NW	3–4	b. c. ◍	29·80	28·00	..
142A	5 23 12 (Anchorage, E side, Fadiffolu Atoll.)	73 37 30	29.iii	17.31	31	N	2	N	2	b. c. ◍	29·28	28·72	..
142B	5 23 12	73 37 06	30.iii	6.35	37	NW	2	..	..	b. c ◍	..	..	..
143	5 15 48 5 13 42	73 22 48 to 73 23 36	30.iii	9.30	797	NW	2	NW	2	b. c. ◍	29·84	28·89	..
144	5 26 06 (Anchorage, W side, Fadiffolu Atoll.)	73 22 24	31.iii	6.37	31	S × E	1	S × E	1	b. c. ◍	29·82	28·06	..
145A	4 58 42	73 16 24	31.iii	17.30	494	NNW	3	NNW	3	b. c. ◍	29·75	29·44	..
145C	4 58 42	73 16 24	1.iv	15.30	494	WNW	3	WNW	3	o. ◍	29·78	28·8	..
145D	4 58 42	73 16 24	2.iv	3.55	494	WNW	3	WNW	3	o. ◍	29·79	..	..
145E	4 58 42	73 16 24	2.iv	7.35	494	WNW	3	WNW	3	b. c. ◍	29·84	28·1	..
146	4 50 18 4 53 00	72 52 48 to 72 55 24	2.iv	13.20	37	WNW	3	WNW	3	b. c. ◍	29·84	29·33	..
147	4 53 12 (Anchorage, Horsburgh Atoll.)	72 54 30	2.iv	16.25	27	WNW	3	WNW	3	b. c. ◍	29·76	30·00	..
148	4 53 12 4 51 24	72 54 30 to 72 53 06	3.iv	6.30	27	NW	3	NW	3	b. c. ◍	..	28·6	..
149	4 49 30	72 51 06	3.iv	12.25	238	NW	3	NW	3	b. c. ◍	29·83	29·28	..
150	4 49 12	72 50 12	3.iv	15.32	423	NNW	3	NNW	3	b. c. ◍	29·76	28·89	..
151	4 50 00	72 50 12	3.iv	16.09	101	NNW	3	NNW	2	b. c. ◍	29·76	28·89	..
152	4 49 24 4 48 42	72 46 30 to 72 40 30	4.iv	8.30	878	WNW	3	WNW	2	b. c. ○	29·84	28·89	..

Stations of H.E.M.S. "Mabahiss".

Hydrological observations.						Transparency of the water (SD reading).		Nature of bottom.	Biological observations.				Remarks.
Surface.			Sub-surface.						Gear.	Depth (metres).	Time.		
Depth (metres).	Temp. (° Cent.).	S. ‰	Depth (metres).	Temp. (° Cent.).	S. ‰	Depth (metres).	Time.				From	To	
..	..	..	..	..	..	..	..	w. m.	G	46	..	..	H_2S present.
0	27·9	34·52	..	..	..	..	..	c. cr. s.	AT	..	..	..	Wire fouled. Net failed to fish
0	28·7	34·14	..	..	..	..	..	cr. s.	G	57	..	..	..
0	28·7	35·17	..	..	..	..	..	c. s.	TD 4	515–525	12.24	13.17	..
..	..	..	..	..	..	..	..	c. s. sh. cr.	G	44	..	..	..
..	..	..	..	..	..	..	..	bl. and w. m.	G	31	..	..	H_2S present.
..	..	..	..	..	..	..	..	cm. m.	G	37	..	..	H_2S present.
0	29·5	34·20	770	7·88	..	..	..	gr. s.	AT	797	11.10	12.18	..
..	..	..	..	..	..	..	..	c. sh. s.	G	31	..	..	..
0	28·78	34·14	..	..	..	34·0	17.43	..	..	37	..	..	..
0	28·74	34·14	50	27·75	34·96	36·5	8.14	gn. m. s.	N 100	50–0	15.50		Vertical haul.
			100	24·40	35·43				N 100	100–0			
			300	11·49	35·07				N 100	300–0			
			400	10·86	35·12				N 100	400–0		17.30	
0	..	34·38	..	..	..	..	..	gn. m. s.	N 100	50–0	3.55		Vertical haul.
									N 100	100–0			
									N 100	300–0			
									N 100	400–0		5.19	
0	29·2	34·29	..	..	..	..	..	..	AT	494	8.10	9.15	..
..	..	..	..	..	..	..	..	sft. cm. m.	OT	37	13.45	14.45	..
..	..	..	..	..	..	..	..	sft. cm. m.	G	27	..	..	..
0	29·2	34·16	..	..	..	..	..	sft. cm. m. (cr. r. ?)	OT	27–37	6.50	7.35	Trawl caught on bottom. Both bridles parted. Trawl lost.
0	29·1	34·42	..	..	..	..	..	cr. r. lth.	G	238	..	..	..
								c. s. sh. cr.	TD 4	311–339	13.28	14.30	..
..	..	..	..	..	..	..	..	hard	G	423	..	..	Grab came up empty.
0	28·7	34·36	..	..	..	..	..	cr. r.	G	101	..	..	..
0	28·67	34·60	860	7·94	..	..	..	gn. s.	TD 4	609–915	10.0	11.0	..

STATION LIST I.—

Station.	Position. N.	Position. E.	Date.	Hour.	Sounding (metres).	Wind. Direction.	Wind. Force.	Sea. Direction.	Sea. Force.	Weather.	Barometer.	Air temp. (° Cent.).	Remarks.
	° ′ ″	° ′ ″	1934.								″		
153	4 45 36 4 42 36	72 52 12 to 72 50 24	4.iv	13.20	256	WNW	3	WNW	3	b. c. ○	..	..	..
154	4 47 00 4 45 30	72 50 54 to 72 47 42	4.iv	15.07	457	NW	3	NW	3	b. c. ◐	29·74	29·44	..
155	4 31 00 4 31 30	72 42 30 to 72 38 00	5.iv	12.30	2249	WNW	3	WNW	3–4	b. c. ◐	29·86	28·89	..
156	4 44 30 4 41 12	72 46 00 to 72 42 48	6.iv	8.50	1317	NW	3	NW	3	b. c. ◍	29·88	28·56	..
157	4 43 48 4 44 00	72 55 24 to 72 54 18	6.iv	15.45	229	WNW	3	WNW	3	b. c. ◍	29·78	28·22	..
158	4 42 30 4 36 48	72 42 30 to 72 48 54	7.iv	8.0	914	WNW	3	WNW	3	b. c. ◐	29·86	28·33	..
159	4 47 30 4 48 00	72 45 18 to 72 46 42	7.iv	12.0	1280	WNW	3	WNW	3	b. c. ◐	29·84	28·06	..
160	4 52 30	72 51 36	7.iv	17.17	37	NNW	3	NNW	3	b. c. ◐	29·76	28·06	..
161	5 04 48 (Anchorage, W side, S. Malosmadulu Atoll.)	72 50 30	8.iv	12.29	46	NNE	1	Calm		b. c. ◐	29·82	28·89	..
162	8 08 30	72 58 00	10.iv	12.55	1829	NNW	1	NNW	3	b. c. ◐	29·82	31·11	..
163	8 15 18	73 01 36	11.iv	9.47	274	NNW	1	NNW	3	b. c. ◐	29·82	30·17	..
164	8 15 24	73 01 30	11.iv	10.23	183	NNE	1	NNE	1	b. c. ◍	..	..	..
165	8 15 12	73 01 30	11.iv	10.53	366	NNE	1	NNE	2	b. c. ◍	29·84	30·33	..
166	6 55 18 6 48 54	67 11 18 to 67 14 00	23.iv	10.0	4793	NW	2–3	NW	3	b. c. ○	29·88	28·39	Slight confused swell
167	7 11 48 7 11 24	63 05 36 to 62 59 30	25.iv	6.35	4042	WNW	3	WNW	3	b. c. ○	29·86	28·44	..
168	7 14 00 7 14 18	60 38 42 to 60 39 30	26.iv	3.30	2937	NE	3	NE	3	b. c. ○	29·81	28·78	Slight SE swell
169	7 16 12 7 17 00	60 33 36 to 60 34 12	26.iv	12.15	2711	E × S	3	E × S	3	b. c. ◐	29·89	29·72	Slight SE swell
170	7 38 48 7 38 00	58 18 30 to 58 25 24	27.iv	6.30	3676	E	3	E	3	b. c. ◐	29·86	28·89	..
171	9 07 06 9 08 48	55 27 06 to 55 31 48	28.iv	17.15	3872	NNW	2	NNW	3	b. c. ◐	29·83	28·89	Slight E swell

Stations of H.E.M.S. "Mabahiss".

Hydrological observations.						Transparency of the water (SD reading).		Nature of bottom.	Biological observations.				Remarks.
Surface.			Sub-surface.						Gear.	Depth (metres).	Time.		
Depth (metres)	Temp. (° Cent.)	S. ‰	Depth (metres).	Temp. (° Cent.)	S. ‰	Depth (metres).	Time.				From	To	
..	..	..	..	..	..	..	..	..	TD 4	256–293	13.44	14.14	..
0	29·2	34·54	..	..	..	..	..	..	AT	457	15.32	16.22	Net badly torn.
0	28·7	34·40	..	..	..	..	..	..	MT	2249	13.50	14.21	..
0	28·9	34·51	..	..	..	..	..	..	AT	?	11.15	12.15	Trawl never on the bottom.
0	28·9	34·45	..	..	..	..	..	cr. r.	TD 4	229	16.00	16.30	..
0	28·7	34·54	..	..	..	..	..	..	AT	786–1170	8.57	9.56	..
0	29·2	34·51	..	..	..	..	..	..	MT	914–1463	13.10	14.03	..
..	..	..	..	..	..	..	..	em. m.	G	37	..	..	H_2S present.
0	29·2	34·54	..	..	..	..	..	c. s.	G	46	..	..	..
0	31·9	34·74	..	..	..	..	..	gy. m.	AT	1829–2051	14.55	15.36	..
..	..	..	..	..	..	..	..	gn. s.	G	274			..
..	..	..	..	..	..	..	..	gn. s.	G	183			..
..	..	..	..	..	..	..	..	gn. s.	G	366			..
0	29·92	35·03	4000	1·78	34·94	42·0	16.30	rd. cl.; m. nd.	MT	4793–4850	11.56	13.56	Net badly torn.
0	29·42	34·97	40	29·05	35·14	45·0	8.18	rd. cl.	HN	40–0	10.30		..
			80	26·40	35·57					90–50			
			100	24·58	35·52					140–100			
			150	19·10	35·35					190–150			
			200	18·39	35·17					300–250		11.55	
			300	12·68	35·14								
			2200	2·43	34·87								
0	29·0	35·39	..	..	..	..	..	r.	MT	2937–3182	5.40	7.40	Frame broken; net badly torn.
0	29·59	35·41	40	27·88	35·53	36·0	14.10	..	HN	40–0	14.40		..
			80	24·88	35·55					90–50			
			100	23·50	35·46					140–100			
			150	19·94	35·41					190–150			
			200	15·66	35·32					240–200		15.40	
			300	12·12	35·23								
			2500	2·33	34·79								
0	28·80	35·53	3500	1·93	34·87	39·0	9.40	gl. oz.	AT	3676	16.0	17.0	..
0	29·12	35·42	2000	3·68	34·87	..	..	..	AT	3840–3872	20.0	22.0	Bigelow tube lost.

STATION LIST I.—

Station	Position. N. °	′	″	E. °	′	″	Date.	Hour.	Sounding (metres).	Wind. Direction.	Wind. Force.	Sea. Direction.	Sea. Force.	Weather.	Barometer. ″	Air temp. (° Cent.).	Remarks.
							1934.										
172	9	40	24	54	33	36 to	29.iv	13.15	4720	NE	2	NE	2	b. c.	29·81	29·22	..
	9	42	18	54	39	00								◐			
173	9	59	30	52	57	36 to	30.iv	9.30	4499	WSW	2	WSW	2	b. c.	29·91	28·33	..
	9	56	42	53	11	42								◐			
174	12	02	06	51	38	48 to	1.v	12.57	865	S	4	S	4	b. c.	29·90	28·78	..
	12	06	06	51	38	00								○			
175	12	37	24	51	21	12 to	1.v	19.20	1618	ESE	4	ESE	4	b. c.	29·86	28·78	..
	12	43	18	51	19	12								○			
176	12	04	06	50	38	36	2.v	9.30	695	S	2–3	S	2–3	b. c. ◐	29·90	27·78	..
177	12	01	54	50	39	12	2.v	13.53	366	NNE	2–3	NNE	2–3	b. c. ◐	29·90	29·33	..
178	12	00	36	50	40	06	2.v	15.50	91	NNE	3	NNE	3	b. c. ◐	29·84	28·61	..
179A	12	02	06	50	40	12	2.v	16.36	310	NNE	3	NNE	3	b. c. ◐	..	..	..
179B	”	”	”		”	”	2.v	16.54	275	NNE	3	NNE	3	b. c. ◐	..	..	..
180	12	03	24	50	40	12	2.v	17.20	366	NNE	3	NNE	3	b. c. ◐	..	..	..
181	13	25	06	51	09	12 to	3.v	7.03	1982	SE	4	SE	4	b. c.	29·92	28·11	..
	13	28	36	51	08	00								◐			
182	13	57	48	51	00	24 to	3.v	15.25	..	SE	3	SE	3	b. c.	29·86	28·89	Slight SE
	13	58	00	51	02	12								◐			swell
183	14	40	06	50	53	36 to	4.v	7.0	1105	SE	2	SE	2	b. c.	29·94	28·89	Slight SE
	14	40	42	50	53	00								◐			swell
184	14	36	06	51	00	18 to	4.v	9.55	1269	SE	2	SE	2	b. c.	29·90	29·33	Slight SE
	14	38	42	50	57	42								◐			swell
185	13	48	06	49	16	48 to	5.v	6.25	2001	E × S	3	E × S	3	b. c.	29·90	28·89	Slight SE
	13	48	36	49	16	24								◐			swell
186	13	32	30	49	13	06 to	5.v	13.30	..	E	4	E	4	b. c.	29·82	28·89	Slight SE
	13	32	00	49	15	18								○			swell

Stations of H.E.M.S. "Mabahiss".

Hydrological observations.						Transparency of the water (SD reading).		Nature of bottom.	Biological observations.				Remarks.
Surface.			Sub-surface.						Gear.	Depth (metres).	Time.		
Depth (metres).	Temp. (° Cent.).	S. ‰	Depth (metres).	Temp. (° Cent.).	S. ‰	Depth (metres).	Time.				From	To	
0	30·1	35·59	..	..	..	..	..	..	N 100	200–0	14.37		510 metres of wire out.
									N 100	400–0			820 metres of wire out.
									N 100	850–0			1500 metres of wire out.
									N 100	2040–0			2600 metres of wire out. Net lost.
									N 200	2091–0		16.37	2665 metres of wire out. Net badly torn.*
0	28·78	35·28	..	..	..	29·0	15.35	w. m.	..	..	..	..	..
0	28·60	35·84	40	26·25	35·79	28·5	14.15	gn. m.	HN	40–0	14.30		Repeat of Sta. 23.
			80	25·02	36·08					90–50			
			100	23·39	35·84					140–100			
			150	17·88	35·52					200–150		15.10	
			200	16·47	35·39								
			800	10·27	35·39								
0	28·22	35·95	1365	6·63	35·16	..	..	gn. m.	..	..	..	..	Repeat of Sta. 30.
0	27·9	36·04	..	..	..	..	..	gn. m. s.	AT	655–732	10.20	11.50	..
..	..	..	..	..	..	..	..	gn. m. r.	AT	274–366	14.20	14.56	Trawl frame badly bent. Net torn.
0	26·9	36·04	..	..	..	..	..	c. gn. s.	G	91	..	..	..
..	..	..	..	..	..	..	..	r.	G	310	..	..	..
..	..	..	..	..	..	..	..	gn. m. s.	G	275	..	..	..
..	..	..	..	..	..	..	..	gn. m. s.	G	397	..	..	..
0	27·85	36·11	1580	5·42	34·90	38·0	9.55	gn. m.	..	..	..	..	Repeat of Sta .31.
0	28·35	36·06	1965	3·59	34·95	22·0	15.30	..	..	..	..	..	Repeat of Sta. 38.
0	29·10	36·29	1000	10·79	35·66	32·0	8.30	..	..	..	..	..	Repeat of Sta. 32.
0	29·5	36·24	..	..	..	..	..	gn. m.	AT	1270	12.05	14.50	..
0	28·3	36·31	..	..	..	..	..	gn. m.	AT	2000	8.45	10.16	..
..	..	..	..	..	..	..	..	..	N 100	250–0	14.16		510 metres of wire out.
									N 100	575–0			880 metres of wire out. Stop slipped.
									N 100	600–0			1150 metres of wire out.
									N 200	952–0		15.16	1500 metres of wire out.*

Station List I.—

Station.	Position. N.	Position. E.	Date.	Hour.	Sounding (metres).	Wind. Direction.	Wind. Force.	Sea. Direction.	Sea. Force.	Weather.	Barometer.	Air temp. (° Cent.).	Remarks.
	° ′ ″	° ′ ″	1934.								″		
187	12 45 30	48 53 42 to	5.v	22.0	1651	SE	3	SE	3	b. c. l.	29·88	28·33	..
	12 44 12	48 53 48								⦷			
188	13 43 18	47 56 54 to	6.v	10.30	528	SE	3	SE	3	b. c.	29·92	28·89	..
	13 46 00	47 50 42								⦷			
189	13 51 30	47 49 12	6.v	16.24	91	SE	3	SE	3	b. c.	29·82	29·00	..
										⦶			
190	13 49 00	47 49 12	6.v	16.50	183	SE	3	SE	3	b. c.	..	..	..
										⦶			
191	13 46 30	47 48 54	6.v	17.18	274	SE	3	SE	3	b. c.	..	..	..
										⦶			
192	13 44 48	47 48 54	6.v	17.40	366	SE	3	SE	3	b. c.	..	..	..
										⦶			
193	13 06 12	46 24 30 to	7.v	7.35	1061	SE	2	SE	2	b. c.	29·92	28·78	..
	13 03 00	46 21 42								⦷			
194	13 16 00	46 20 24 to	7.v	13.0	220	ENE	2	ENE	1	b. c.	29·94	29·44	..
	13 16 36	46 14 00								⦷			
195	12 31 06	45 21 00	8.v	7.0	1042	SE	2	SE	2	b. c.	29·94	29·17	..
										⦶			
196	12 38 12	45 11 00	8.v	10.40	375	ESE	3	ESE	3	b. c.	29·96	29·44	..
										⦷			
197	11 57 18	45 16 24 to	13.v	16.0	1063	ENE	3	ENE	3	b.	29·88	29·17	Slight ESE
	11 59 06	45 16 18								◯			swell
198	11 20 24	45 06 00 to	13.v	23.35	1491	E	4	E	4	b.	29·88	28·11	Slight ESE
	11 22 24	45 05 12								◯			swell
199	10 59 12	45 02 42 to	14.v	5.15	1434	E	3–4	E	3–4	b.	29·86	28·33	Slight E swell
	10 59 06	45 02 06								◯			
200	11 56 48	43 38 42 to	15.v	8.15	1463	E	2	E	2	b. c.	29·88	29·78	..
	11 57 00	43 35 12								⦷			
201	12 12 30	43 45 54 to	15.v	13.15	375	E	3	E	3	b. c.	29·88	29·72	..
	12 12 00	43 41 30								⦶			
202	12 23 12	43 54 12 to	15.v	17.0	439	E	3	E	3	b. c.	29·80	29·78	..
	12 24 00	43 51 36								⦶			
203	13 35 06	42 35 24 to	16.v	7.10	229	ESE	3	ESE	3	b. c.	29·86	28·72	..
	13 35 24	42 34 30								⦶			
204	13 41 24	42 31 30 to	16.v	9.20	110	ESE	3	ESE	3	b. c.	..	..	..
	13 42 30	42 31 12								⦶			
205	13 47 30	42 28 18	16.v	11.20	177	N	3	N	3	b. c.	29·86	29·33	..
										⦶			
206	13 57 30	42 35 24	16.v	13.01	256	N	3	N	3	b. c.	..	..	..
										⦶			
207	14 08 56	42 19 00	16.v	16.35	375	N	3	N	3	b. c.	29·76	28·78	..
										⦷			
208	15 48 30	41 30 30	17.v	6.0	732	NW	3	NW	3	b. c.	29·86	28·22	..
										⦶			
209	15 54 36	41 13 00	17.v	12.10	366	NW	3	NW	3	b.	29.84	29·00	..
										◯			

Stations of H.E.M.S. "Mabahiss".

Hydrological observations.						Transparency of the water (SD reading).		Nature of bottom.	Biological observations.				Remarks.
Surface.			Sub-surface.						Gear.	Depth (metres).	Time.		
Depth (metres).	Temp. (° Cent.).	S. ‰.	Depth (metres).	Temp. (° Cent.).	S. ‰.	Depth (metres).	Time.				From	To	
0	28·19	36·27	1000	11·53	35·90	..	..	gy. gn. m.	..	..	..	..	..
0	28·94	36·27	200	15·66	35·66	..	..	gn. m.	AT	?	11.40	12.42	Net came up empty.
			400	13·82	35·44				AT	528	13.50	14.50	Net filled with mud and burst.
0	29·2	36·29	..	..	..	..	..	gn. s. m.	G	91	..	..	H_2S present.
..	..	..	..	..	..	..	..	gn. s. m.	G	183	..	..	..
..	..	..	..	..	..	..	..	gn. s. m.	G	274	..	..	..
..	..	..	..	..	..	..	..	sft. d. gn. m.	G	366	..	..	..
0	23·69	36·38	1000	10·86	35·81	..	..	gn. m.	AT	1061–1080	9.30	11.0	..
..	..	..	..	..	..	..	..	..	AT	220	13.30	15.33	..
0	28·81	36·29	..	..	..	44·0	8.50	..	..	..	..	..	..
0	29·30	36·29	..	..	..	31·5	12.30	..	..	..	..	..	Repeat of Sta. 36.
0	28·98	36·26	..	..	..	31·0	16.20	..	..	..	..	..	Repeat of Sta. 20
0	27·95	36·29	..	..	..	..	..	..	..	..	..	..	Repeat of Sta. 21.
0	28·72	36·38	..	..	..	28·5	6.55	..	..	..	..	..	Repeat of Sta. 18.
0	30·10	36·53	1175	15·96	37·39	..	..	..	..	..	..	..	Repeat of Sta. 14.
0	29·48	36·42	350	17·86	37·01	35·5	14.45	..	..	..	..	..	Repeat of Sta. 13.
0	29·05	36·44	500	22·30	39·38	26·0	17.45	..	..	..	..	..	Repeat of Sta. 12.
0	28·28	36·42	220	22·12	40·44	23·5	8.15	..	..	..	..	..	Repeat of Sta. 9.
0	28·62	36·47	95	22·54	40·43	22·5	10.20	gn. m. r.	G	110	..	..	Repeat of Sta. 8.
0	28·9	36·47	..	..	..	..	..	r.	G	177	..	..	..
0	28·74	36·62	241	21·75	40·55	23·5	14.05	gr. br. s. m. r.	G	256	..	..	..
..	..	..	..	..	..	..	..	gr. br. m. pt.	G	375	..	..	..
0	27·86	37·25	700	21·65	40·59	30·0	7.25	gr. br. m. r.	TD 4	732–805	8.54	9.56	..
0	29·0	38·04	..	..	..	..	..	gr. br. m. r.	TD 4	366	12.33	13.00	..

Station List II.—

Station.	Position. N.	Position. E.	Date.	Hour.	Sounding (metres).	Wind. Direction.	Wind. Force.	Sea. Direction.	Sea. Force.	Weather.	Barometer.	Air temp. (° Cent.).	Remarks.
	° ′ ″	° ′ ″	1933.								″		
M.B. I (*a*)	13 39 30	42 43 00	17.ix	10.0	29	..	..	..	..	..	..	..	..
	Bay between Gt. Hanish and Suyul Hanish Islands, Red Sea												
(*b*)	.. ....	.. .. ..	17.ix	11.0	29	..	..	..	..	..	..	..	..
(*c*)	.. .. ..	.. .. ..	17.ix	15.30	26	..	..	..	..	..	..	..	..
(*d*)	.. .. ..	.. .. ..	17.ix	16.0	26	..	..	..	..	..	..	..	..
M.B. II (*a*)	17 33 30	56 01 30	28.x	9.55	11	..	..	..	..	..	..	..	..
	Coastal zone N. of Jezirat Hallaniya, Khorya Morya Islands, Arabian coast												
(*b*)	.. .. ..	.. .. ..	28.x	11.30	26	..	..	..	..	..	..	..	..
(*c*)	.. .. ..	.. .. ..	28.x	12.45	29	..	..	..	..	..	..	..	..

Stations of Motor Boat.

Hydrological observations.						Transparency of the water (SD reading).		Nature of bottom.	Biological observations.				Remarks.
Surface.			Sub-surface.						Gear.	Depth (metres).	Time.		
Depth (metres).	Temp. (° Cent.).	S. °/₀₀.	Depth (metres).	Temp. (° Cent.).	S. °/₀₀.	Depth (metres).	Time.				From	To	
..	..	..	..	..	..	..	..	s. sh. cr.	RD	?	10.0	10.20	Net apparently not on bottom.
..	..	..	..	..	..	..	..	s. sh. cr.	RD	29	11.0	11.25	..
..	..	..	..	..	..	..	..	cr. r.	RD	26	15.30	..	Dredge fast in bottom.
..	..	..	..	..	..	..	..	s. sh. cr.	RD	26	16.0	16.15	..
..	..	..	..	..	..	..	..	c. s.	RD	11	9.55	10.25	..
0	26·1	36·00	10 20	25·9 25·5	35·90 35·905	..	..	..	..	..	..	..	..
..	..	..	..	..	..	..	..	c. s.	RD	29	12.45	1.15	..

JOHN MURRAY EXPEDITION TO THE INDIAN OCEAN, 1933-34.

TRACK OF VOYAGE OF H.E.M.S. "MABAHISS"

BRITISH MUSEUM (NATURAL HISTORY)

THE

JOHN MURRAY EXPEDITION 1933–34

SCIENTIFIC REPORTS

VOLUME I. No. 2

TOPOGRAPHY

WITH

AN APPENDIX ON MAGNETIC OBSERVATIONS

BY

W. I. FARQUHARSON, LIEUTENANT-COMMANDER, R.N.

WITH SIX PLATES AND SIX CHARTS

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W. I. FARQUHARSON, Lieutenant-Commander, R.N.

WITH SIX CHARTS AND SIX PLATES.

(*For List of Charts see p.* 61.)

I. ECHO-SOUNDING MACHINE.

This was the Admiralty Recording Echo-sounding Gear, Acadia type, manufactured by Henry Hughes & Son, Ltd.

It is divided into three parts, Transmitter, Hydrophone and Receiver.

Transmitter. (Pl. I, upper fig.)

Fitted below the floor plates of the boiler room and supplied with air at 100 lb. pressure by a small electrical compressor in the engine-room. The transmitter consists of a steel hammer operated by compressed air, the blow being distributed through pressure chambers to the ship's hull. The air supply is controlled by a solenoid operating an electro-magnetic valve in the solenoid housing. The current to this solenoid is supplied from the hammer switch gear in the receiver. After a blow the hammer is lifted to the top of the cylinder again by means of low-pressure air from the main supply passing through a reducing valve.

Hydrophone. (Pl. I, lower fig.)

Mounted on a sluice valve situated on the ship's hull below the fish-hold, the vibrations of an incoming echo being transmitted through a diaphragm to the microphone button.

Receiver. (Pl. II.)

Fitted on the after bulkhead of the wheel-house. This consists of an electric motor operating the switch gear for the transmitter, the amplifier and the recording apparatus. When the main switch is made, current is supplied to the hammer switch gear and thence to the solenoid in the transmitter. This solenoid closes the valve against the air supply from the compressor. The switch gear is revolved by gearing from the electric motor, and as the inner brush passes over the gap the circuit to the transmitter is broken. This allows the air to open the valve and to drive the hammer down. The vibrations of the resulting echo transmit a current from the microphone to the amplifier. Thence the amplified current passes to the stylus traversing the recording paper, which is sensitized by the starch iodide process. Any disturbance reaching the hydrophone is thus recorded on the paper by a dark stain due to the liberation of iodine.

The electric motor revolves the hammer switch gear once every $2\frac{1}{2}$ seconds. This is the time taken for a sounding of 1000 fathoms to reach the bottom and return ; allowing for the double journey it is therefore the equivalent of a velocity of sound of 800 fathoms per second. Gearing from the shaft of the motor also operates two switch drums, and a roller which draws the recording paper downwards. The first of these switch drums allows current to pass to the stylus at the beginning and the end of its passage across the paper, thus marking the zero lines. As the contact for the second zero line is made a quarter of a revolution after the first, the zero lines are thus 250 fathoms apart.

The second switch drum is so connected by gearing to the motor shaft that it only makes contact once in every 24 revolutions of the hammer switch ; thus current is supplied to the stylus to mark the record once a minute.

Phase.

It has been shown that whereas the hammer switch turns through one revolution in a time equivalent to that taken for a sounding of 1000 fathoms to be transmitted and received, the width of the recording paper is only sufficient for a sounding of 250 fathoms. Soundings greater than the latter depth are recorded by advancing the position of the gap by steps of 100 fathoms up to 1000 fathoms. The hammer switch is graduated for these steps, and the reading uppermost on the switch will show the number of hundreds of fathoms to be added to the sounding shown on the record. In depths greater than 1000 fathoms the switch will have passed through one revolution before the echo is received, and similarly in 2000 fathoms it will have completed two revolutions.

In order to ascertain the correct setting of the switch to pick up a sounding a telephone circuit is fitted. The selector switch controls a circuit in series with the hammer switch, and it can be operated so that only one hammer-blow is transmitted. Using the head-phones a blow is transmitted; the number of revolutions made by the hammer switch before the echo returns gives the depth in thousands of fathoms. The position of the brush relative to the graduations on the hammer switch will allow the depth to be read to the nearest 100 fathoms. The switch can now be set to the phase suitable for recording.

Recording Paper.

A drum of paper lies at the back of the receiver and is drawn by the roller over a wick at the top of the tank. The paper is thus sensitized, and after passing under the

stylus is drawn over a heater, which dries it. The record is then ready for measurement. A scale compensated for the shrinkage of the paper is used. The results can then be worked up, the recorded soundings having to be corrected for the difference between the velocity of sound in any particular area and the velocity of 800 fathoms per second for which the machine is graduated.

The motor is controlled by a governor which eliminates fluctuations of the ship's voltage, and it can be adjusted to run the machine for velocities slightly different to 800 fathoms per second. However, complications to the working up of results are introduced if this speed is not adhered to, especially as the time record will no longer represent minutes.

Throughout the Expedition the machine was required to be in use almost continuously while the ship was under way. This meant that on ocean passages the machine was running for periods of 36 hours to 72 hours without stopping. The echo-sounding gear stood up to this test successfully for at least 90% of the work required from it. The time lost was largely due to breakdowns of the transmitter solenoids. While the hammer is in operation there is a certain amount of vibration in the transmitter, which in time damages the insulation of the leads to the solenoid. In the early part of the expedition more time was spent in locating the source of trouble than was necessary later, when experience reduced very considerably the time lost in diagnosing the fault. Apart from the solenoids, no other part of the gear gave any considerable trouble. The hydrophone required no attention whatever, and the air compressor, except for occasional changing of brushes, worked satisfactorily throughout the expedition.

A spare transmitter was carried, and it was necessary to ship this when the cylinder of the original one cracked. This fracture was probably due to fatigue in the metal, as it occurred after the machine had been running continuously for about six months. Towards the end of the expedition the amplifier gave a certain amount of trouble. Two or three of the valves and two of the resistances burnt out, but this also only occurred after they had been working satisfactorily for very long periods. The damaged resistances were replaced by ones provided by the Eastern Telegraph Company at Aden. The damaged solenoids were also repaired at the Seychelles by this company.

Taking into account the lack of a workshop and facilities for carrying out repairs on board, it is considered that the machine ran very successfully. Many of the stoppages would probably have been avoided in a ship carrying a trained electrician with a little time to devote to care and maintenance.

II. COMPARISON BETWEEN ECHO AND WIRE SOUNDINGS.

Station.	Echo.	Sounding wire.	Remarks.
1	1205	1230	An indefinite wire sounding, no bottom-sample obtained.
2	551	560	..
3	1145	1190	Wire not quite up and down.
5	513	520	..
9	134	137	..
10	30	30	..
12	264	260	Not simultaneous.

Station.	Echo.	Sounding wire.	Remarks.
13	226	228	..
15	576	569	Not simultaneous.
16	102	101	..
17	467	472	..
20	619	632	..
21	830	825	Not simultaneous.
23	519	529	..
25	339	345	..
29	1133	1134	..
32	644	659	..
33	708	710	..
34	559	564	..
35	241	246	..
38	1344	1340	..
39	1179	1188	..
47	57	61	..
52	57	55	..
55	434	438	..
58	659	685	Not quite simultaneous on slope.
59	1065	1081	..
61	1257	1265	..
62	1035	1041	..
64	245	245	..
65	496	497	..
66	333	335	..
70	107	108	..
71	56	58	..
76	1798	1804	..
93	2183	2193	..
100	2779	2800	..
106	116	118	..
108	427	432	..
109	350	351	..
110	180	181	..
112	62	64	..
116	140	140	..
117	486	494	..
118	978	980	..
119	658	669	..
120	1603	1593	..
121	506	504	..
122	407	410	..
126	114	116	..
127	2237	2276	..
129	1396	1404	..

Station.	Echo.	Sounding wire.	Remarks.
130	2369	2395	..
132	2232	2302	Not up and down.
133	1851	1918	..
134	2315	2354	..
135	1491	1512	..
137	1039	1060	Wire sounding not definite.
140	284	287	..
143	436	437	..
166	2621	2624	..
167	2210	2220	..
170	2010	2026	..
173	2433	2466	..
180	1031	1084	..
188	289	293	..

The echo sounding was therefore usually about $1\frac{1}{2}\%$ less than the wire sounding. The wire soundings were obtained by using a 'Bigelow' bottom sampler on the hydrographic wire. This wire has a considerably larger cross-section than the Lucas wire usually used, and this greater area exposed to the sub-surface currents probably accounts for the excess of the wire soundings.

III. RED SEA AND GULF OF ADEN.

The soundings in the Red Sea were mainly taken with a view to testing the echo-sounding machine. They were also taken at each place where it was desired to make a station. The soundings obtained were found to be in good agreement with those already charted. The machine was first run in depths suitable for recording between the 100-fathom line in the Strait of Jubal and Hurghada. Its possibilities were illustrated almost immediately, for the record showed, when south-west from Shadwan Island, an uncharted bank rising to 90 fathoms from depths of 291 fathoms on its eastern side and falling to depths of 251 fathoms on its western side.

It was decided to make the first station in the vicinity of the 1265 fathom sounding in latitude 25° 24′ N., longitude 36° 12′ E.—by far the greatest depth charted in the northern end of the Red Sea. The existence of this deep hole was confirmed by the echo. The station was made in a depth of 1205 fathoms.

Gulf of Aden. (Chart 1, and Pl. III.)

Soundings in this area were obtained in the course of five of the ten cruises.

No. 1. At the western end of the Gulf.

No. 2. Between Aden and Berbera, then along the southern side of the Gulf to Cape Guardafui, with the return passage along the northern side of the Gulf.

No. 3. Zigzagging down the centre of the Gulf while on passage from Aden to Karachi.

No. 9. A few soundings were obtained at the eastern end of the Gulf, but not on passage to Aden, due to a failure of the amplifier of the echo-sounding machine.

No. 10. Soundings were obtained in the western end of the Gulf, mainly in the vicinity of those already obtained in No. 1.

The Gulf consists of a series of ridges and troughs in its centre. At the western end the direction of the contours is from east to west. In the middle and at the eastern end the direction of these contours changes to a direction from north-east to south-west.

From the soundings obtained in the western end of the Gulf it appears that the deep gully of over 100 fathoms, which commences in the Red Sea south of the Hanish Islands, can be traced for a further 75 miles into the Gulf.

The gully, after passing to the south-westward of Perim, gradually deepens to 200 fathoms, running parallel to the 100-fathom line. The gully is bounded on its south side by a long spit of less than 200 fathoms running to the eastward from the French Somaliland Coast. About 35 miles to the eastward from Perim the gully deepens to 300 fathoms, and 40 miles further on merges into the general depth of 400 fathoms.

The spit on the southern side of this gully separates it from another and much deeper gully, running out from the Gulf of Tajura.

The westernmost charted indication of this gully is the sounding of 513 fathoms at the entrance to the Gulf of Tajura. It is supposed that this sounding is connected with one of nearly 1000 fathoms obtained by " Mabahiss " at Station 14 in latitude 11° 56′ N., longitude 43° 38′ E. In this position the depth increased very abruptly from a level plateau to the south-east of 260 fathoms and a similar depth to the north. This gully can be traced for a distance of 165 miles to the eastward from Obokh before it merges into the general depth. In all, this gully was crossed seven times, mainly in the vicinity of the 45th meridian, in which positions the depth was neither so great, nor the descent so abrupt. The depths obtained in the eastern lines over the gully varied between 656 and 785 fathoms, the charted depths further to the westward being between 688 and 839 fathoms.

About the 45th meridian the gully is bounded on its northern side by a ridge having depths of between 285 and 350 fathoms, rising from depths of 500 to 600 fathoms which lie still further north. The southern side of the gully rises steeply to depths of a little over 400 fathoms, then deepens gradually to 700 fathoms and more rapidly to 800 fathoms.

The middle and eastern parts of the Gulf appear to consist of a series of ridges running from the north-east to the south-west, though this may be modified at the extreme eastern end where soundings are sparser, and it becomes increasingly difficult to connect the various groups of shallow soundings.

The changes in depth are frequently extremely abrupt. The general depths of the Gulf increase gradually from 900 to 1400 fathoms, although much greater depths occur in places. The ridge that runs south-westward from Ras Fartak was followed for the greater part of its length. The depths on this ridge are between 700 and 800 fathoms, dropping abruptly on its eastern side to over 2000 fathoms. Towards its northern end there are charted two soundings of over 2700 fathoms, representing a descent of nearly 12,000 feet. These depths are considerably greater than any other found in the Gulf of Aden or the Arabian Sea. The ridge is indicated by soundings for a distance of about 120 miles with the gully continuing alongside it. It is about the same height along its whole length,

but the gully decreases in depth until both merge into the general depth of the Gulf. The ridge overlaps the shallow bank extending to the northward from Bander Alula. The depth between the ridge and the bank is about 1300 fathoms, and it appears that water at a greater depth than this has no access to the deeper water outside the Gulf.

The least depths obtained in the middle of the Gulf were two soundings situated near the 50th meridian, one of 325 fathoms, the other of 382 fathoms. These appear to be situated on a ridge running in a similar direction to that from Ras Fartak. This ridge has also a gully on its eastern side with depths of nearly 2000 fathoms. One afternoon was spent in running parallel lines of soundings in the vicinity of the 325-fathom sounding. It appeared as a peak lying in an easterly and westerly direction situated on a ridge of about 900 fathoms running from the north-east to south-west.

Quite possibly less water existed in other parts of the main ridge as the ship's course was parallel to its summit. About 75 miles to the north-eastward of the 325-fathom depth the soundings again shoaled to 382 fathoms. This latter depth was not examined and less water may exist. Another shoal sounding, 200 fathoms, is charted in latitude 14° 28′ N., longitude 53° 11′ E., but not enough soundings have been taken in its vicinity to trace any ridge on which it may be situated.

The gullies appear to be invariably associated with the ridges, the greatest depths being situated immediately to the eastward of the ridges.

The line of soundings run just south of the 12° parallel from the 47th meridian towards Bander Alulu did not reveal any great irregularities, and for the greater part of the way the bottom was quite flat. Similarly, soundings taken parallel to the north coast were regular, with one exception in latitude 13° 39′ N., longitude 48° 17′ E., where the depth rose steeply from 730 fathoms on either side to 520 fathoms. It therefore appears that these ridges, lying in the centre of the Gulf, are not connected with the mainland on either side, but merge into the general depths of the Gulf before reaching the coast. It seems probable that where the general depth in the centre of the Gulf is over 1100 fathoms, the merging of the ridges into the sides of the Gulf takes place at about the 1000-fathom line.

IV. ARABIAN SEA AND ENTRANCE TO PERSIAN GULF. (Chart 2, and Pl. III.)

Soundings were taken in this area throughout the latter half of Cruise 3 and Cruise 4.

Between the Khorya Morya Islands and Ras al Hadd, the approaches to the coast were all similar in appearance, the depth decreasing very rapidly from the 1000 fathom to the 500-fathom line, then more gradually to 250 fathoms, after which it shoals steeply again to about 60 fathoms. The slopes are extremely irregular, consisting of alternate slopes and valleys running out to seaward, in appearance similar to that of a mountain side. While steaming along a course parallel to the shore in the vicinity of the 100-fathom line, the soundings were never constant, varying perhaps from 60 to 360 fathoms in very short distances. The similarity to a mountain side was illustrated by the large quantities of scree dredged off the slopes of the Khorya Morya Islands.

A station was made in the vicinity of the southernmost of the San Carlos Banks, north of Ras Madraka. The bottom sample obtained did not reveal the existence of coral on the bank, and a brief examination of the bank and soundings taken from the dinghy showed no soundings less than 5 fathoms. The published chart shows the bank to have the appearance of a lagoon with soundings of less than 6 feet around its edge, and the nature of the bottom to be coral. The bank appeared to be quite flat with a

general depth of 6 fathoms, and though the examination was too brief to be conclusive, it seems probable, in view of the swell, that if considerably less depths existed, the sea would have been breaking on the weather side of the bank.

Soundings were taken in a position about 13 miles from Ras al Hadd, where H.M.S. "Ranger" reported a shoal sounding of 55 fathoms in 1885. No indications were found to suggest the probability of such shoal water existing, but many irregularities occur between this position and the mainland.

Murray Ridge.

From Ras al Hadd the ship proceeded in an easterly direction to cross the position of a sounding of 951 fathoms charted in latitude 22° 20′ N., longitude 62° 18′ E. The soundings gradually deepened to a level bottom of about 1700 fathoms until this position was reached, when the soundings rose abruptly to 648 fathoms. The ridge was crossed, and in about 2 miles the depth had increased again to 1050 fathoms. Three miles to the northward the depth was 1250 fathoms, the ship then proceeded south and the depth decreased again to 617 fathoms about 2 miles southward of the 648-fathom sounding. Continuing to the southward the depth increased in about 13 miles to 1670 fathoms. This ridge was crossed twice on the next cruise. The first crossing was made diagonally, and the least depth obtained, 480 fathoms, was 55 miles southward from the position of the 648 fathoms; and the second 104 miles to the southward, when the depth was 1321 fathoms. The general depth in this area is 1820 fathoms. This ridge appears to be the continuation of one of a series of banks that run in a south-westerly direction from Karachi, possibly a submerged connection of the Pab Mountains. It differs, however, in one respect, in that while it appears to be steep to, and uneven on its summit, the others appear to be more in the nature of shelving banks. In longitude 64° E. three separate banks appear. The northern one rises from 1730 to 964 fathoms and falls to 2000 fathoms on its southern side, from which the second ridge rises to 790 fathoms. The third bank rises to 413 fathoms, and is probably separated from the second by a depth of about 1200 fathoms. The soundings on the two northerly banks and the continuation of the third ridge towards Karachi were obtained by "Mabahiss". The soundings on the summit of the third bank were taken by one of the German cruisers.* The gully of 2000 fathoms that separates the two northern banks is similar to the one that lies on the eastern side of Murray Ridge. It is the existence of these gullies that make it probable that they are connected, and that the Murray Ridge is a continuation of the northern bank.

South of the southernmost crossing of the ridge by "Mabahiss" echo soundings of 2200 and 2300 fathoms were obtained by one of the German cruisers.* As these soundings are comparable in depth only with those obtained in the gully further to the north, it suggests that the gully is continued further to the south. The ridge itself may be continued to the southward, possibly for a great distance, as its track would lead through a group of shallow soundings in latitude 16° N., longitude 60° E. These shallow soundings may, in turn, be connected with the Carlsberg Ridge in the Indian Ocean.

The Makran Basin.

Northward of the line joining Ras al Hadd to the Murray Ridge, the depth increases from 1750 fathoms to 1830 fathoms—the general depth of the basin. This basin appears

* 'Beiheft zu den Nachrichten für Seefahrer,' No. 51, 1932, and No. 25, 1934.

to have no outlet to water of a similar depth, and the parts traversed by "Mabahiss" showed a perfectly smooth bottom. To the north the basin is bounded by a series of ridges that run parallel to and about 60 miles from the Makran Coast. On the south-eastern side the basin is bounded by the banks running out from Karachi. The north-western arm extends towards the entrance to the Persian Gulf along the southern side of the Gulf of Oman. The north-eastern arm extends for nearly 200 miles, shoaling very gradually, towards the low ground of Sonmiani Bay lying between the Makran Coast Range and the Khirtar and Pab Mountains.

Makran Coast.

The northern edge of the basin is formed by a barrier that usually rises between 400 and 500 fathoms from the general depth. This barrier was crossed eight times by "Mabahiss". In the 60 miles that separate this barrier from the mainland there lies a series of ridges and valleys running parallel to the coast. The ridges appear to be similar to the mountain chains of the coast. The submerged valleys in most cases contain water of depths 200 or 300 fathoms deeper than the barrier. It seems probable that in many cases the water in these valleys is cut off from water of a similar depth in the basin. On the north coast these irregularities appear to continue right up to the 100-fathom line in the head of the Gulf of Oman. The 100-fathom line is by contrast extremely regular.

Oman Coast.

In the Gulf of Oman no soundings as deep as those of 1900 and 2000 fathoms, shown on the published charts, were obtained. On the contrary the depths showed a gradual decrease from 1830 fathoms in the basin towards the head of the Gulf. On the western side of the basin a line of soundings was run about 30 miles off the coast of Oman. Where the depths were less than 1500 fathoms the soundings were very irregular. These irregularities are probably due to spurs running to seaward from the 100-fathom line as happens southward of Ras al Hadd. They may also be due to the presence of submerged valleys and ridges running parallel to the coast similar to those on the Makran Coast. The latter seems to be the case off Muscat.

The sections along the 64th meridian and the parallel 22° 30′ N. were drawn from the contours suggested by soundings in the vicinity. The contours in the vicinity of Murray Ridge are open to doubt. It may be that the three different groups of shallow soundings shown on the ridge are separated by deep water. In this case each group would appear to be continuations of the three banks to the north-westward. A line of soundings run from the entrance of the Gulf of Oman in a south-easterly direction crossing the banks at right angles would settle this question.

The shallow soundings obtained by one of the German cruisers to the southward from Ras Madraka suggest a continuation of the ridge, on which the Khorya Morya Islands are situated, for a long way to the eastward.

V. INDIAN OCEAN AND ARABIAN SEA. (Chart 3, and Pl. IV.)

In all, four crossings of the ocean were made, the first from a position 135 miles east of Masira Island on the Arabian Coast, approximately along the parallel 20° N. towards Bombay, the second diagonally across from Bombay to Mombasa, the third

approximately parallel to the second from a position 250 miles east from Mafia Island to Kardiva Channel in the Maldive Islands *via* the Seychelles; the fourth was made from Kardiva Channel towards Cape Guardafui.

In addition three lines of soundings were run to the eastward of the Maldive Islands.

Carlsberg Ridge.

On each occasion of making the Ocean passage a ridge was crossed dividing the north-eastern and south-western halves of the Ocean.

The northern crossing, with a depth of 480 fathoms rising from 1800 fathoms on the western side and falling to a depth of over 2000 fathoms on its eastern side, has been described in the section on the Arabian Sea and Entrance to Persian Gulf.

The second crossing between latitudes 9° and 10° N. was made in bad weather, the water-noises and rapid fluctuations in depth making it impossible to keep a continuous record. The least sounding obtained was 1636 fathoms, but the probability is that less water exists.

The third crossing was in latitude 7° N., and the least depths obtained were 1361, 1209 and 1232 fathoms, and 75 miles to the westward 1578 fathoms. The soundings were all isolated by depths of about 2000 fathoms.

The fourth crossing was between latitudes 1° and 2° N.; the least water obtained was 858 and 958 fathoms, separated by depths down to 2000 fathoms.

In addition to these crossings, the ridge was crossed three times by the German cruisers; one in latitude 11° N., where soundings of 1651, 1673 and 1651 fathoms were obtained; the next between latitudes 1° S. and 0°, where soundings of 1360, 1395 and 1400 were obtained. The southern crossing was in latitude 4° S., the least depth being 1447 fathoms. Less water may exist in the vicinity of these German soundings if the record was not a continuous one.

The ridge was also crossed by the "Dana" in a direction close to our own southern crossing, and it was from the results of this crossing that Dr. Johannes Schmidt postulated the existence of the ridge and gave to it the name Carlsberg.

Apart from these echo soundings, there are charted between the latitudes of Socotra and the Chagos Archipelago a sounding of 850 fathoms in latitude 10° N., and soundings of 1253, 1255 and 1364 fathoms in latitude 3° S., with depths of over 2000 fathoms close to the eastward.

Along the supposed track of the ridge the greatest distance between lines of echo soundings is 500 miles. In this gap only two soundings, each of 2100 fathoms, are charted. As the general depth of the ocean is about 2500 fathoms, and fluctuates with great rapidity in the vicinity of the ridge, these two soundings should indicate the continuity of the ridge.

From the 850-fathom sounding, south-eastward of Socotra, the ridge appears to run south-eastward to the Equator, where it turns to the southward. The existing soundings do not suggest that the highest part of the ridge is connected with the Chagos Archipelago, but that it continues to the southward and is connected to the soundings of 1458 and 1442 fathoms in latitudes 12° S. and 15° S., and that these in turn are part of the ridge on which the Island of Rodriguez is situated.

The existing soundings to the south of Socotra are extremely sparse and erratic, but they suggest that the Island of Abd al Kuri may be situated on a ridge connected to the 850 sounding to the south-eastward, and the possibility that a similar ridge running from the south-eastern extremity of Socotra may exist.

The soundings also suggest that the ridge may turn or branch to the northward before reaching Socotra and be continued a long way, with a possibility of eventually connecting with the 480-fathom sounding obtained in the first crossing of the Arabian Sea.

Until many more soundings are obtained in this area it is not possible to draw with any degree of certainty the contours of the ocean bed.

The first, second and third crossings of the ridge were made approximately at right angles to its general direction. The fourth was made at each end at an angle of about 10° to the ridge, and in the centre at about 30° to the ridge. In the section of this last crossing shown in the diagrams, the presence of the ridge is indicated over more than half of the passage.

The ridge as a whole presents the appearance of a series of sharp folds gradually rising from the bed of the ocean and culminating in two or more folds of approximately equal height.

The section shown for the second crossing is only very approximate, owing to the scarcity of soundings, and only represents the appearance suggested by soundings in the vicinity.

North-Eastern Basin.

The basin lying to the eastward of the ridge has an average depth of 2400 fathoms, and is bounded on the east by the Maldives and Laccadives, to the south by the Chagos Archipelago, and on the north by the bank running to the south-westward from Karachi. That part of the basin sounded over by "Mabahiss" was found to have a consistently smooth bottom except in the proximity of the Carlsberg Ridge, the depth steadily increasing towards the centre of the basin. This basin is probably connected with the deep water to the south-eastward by the channel between the Chagos Archipelago and Addu Atoll, in the centre of which echo soundings of 1900 fathoms were obtained.

South-Western Basin.

The basin to the south-west of the Carlsberg Ridge has an average depth in its northern part of about 2700 fathoms. This basin appears to be connected with deep water to the south between Madagascar and Nazareth Bank on the western side of the Seychelles, and also immediately to the east of the Seychelles. To the north the deep water may be continued up into the Arabian Sea unless Socotra and the Carlsberg Ridge are connected. The Seychelles are situated on a plateau of less than 1000 fathoms stretching from Mauritius through Cargados Carajos, Nazareth Bank and Saya de Malha Bank. The general direction of the northern part of this plateau is to the north-west. The southern part of this south-western basin is therefore divided for a large proportion of its extent.

Soundings in the basin are extremely sparse, consisting mainly of the two lines of soundings run by "Mabahiss", one in the north between Mombasa and Bombay, and the other from Mafia Island towards Kardiva Channel, soundings obtained by ships on the route from Cape Guardafui to the Seychelles, and the echo soundings taken by the German

cruisers between Mombasa, the Seychelles and Maldives. On the route from Cape Guardafui to the Seychelles the depths lie between 2600 and 2900 fathoms, the most notable exceptions being a depth 2044 fathoms situated 150 miles north from the Seychelles, depths of 1200, 2100 and 2200 fathoms about 300 miles from the Seychelles, and a depth of 2000 fathoms 510 miles from the Seychelles. These soundings suggest the possibility of a continuation of the Seychelles plateau to the northward in a modified form. On the other hand, the general direction of the plateau and of the Carlsberg Ridge make it more probable that the contours run in a north-westerly direction in the northern part of the basin. Unfortunately no soundings, except in the immediate vicinity of the islands, exist in this direction from the Seychelles.

The northern line of soundings by " Mabahiss " in this basin only revealed one irregularity, a sounding of 1905 fathoms rising nearly 5000 feet from the surrounding depths, so that with this exception, any ridges that may exist must merge into the general depths of the Ocean before reaching the coast, as appears to be the case in the Gulf of Aden.

The only other marked irregularity, except for those in the immediate vicinity of the Seychelles, was found by " Mabahiss " about 250 miles to the eastward of the Seychelles, a sounding of 1570 fathoms also rising about 5000 feet from the surrounding depths.

The 1905 and 1570 soundings obtained by " Mabahiss ", and the soundings of 1200 and 2200 fathoms on the route from Cape Guardafui to the Seychelles, if connected, would lie on a ridge lying parallel to and with, approximately, the same direction as the Carlsberg Ridge. A study of the sections of crossings 2 and 3 in the diagrams emphasizes the similarity of the contours of the 1905- and 1570-fathom peaks and their positions relative to Mabahiss Ridge. If this additional ridge exists, it would appear to branch off the Seychelles-Mauritius Plateau to the north of Saya de Malha Bank.

To the north-westward of the Seychelles certain irregularities do exist. Soundings of 918 and 876 fathoms, rising from about 2000 fathoms on their western and eastern sides, were obtained by " Mabahiss ", 34 miles from the bank ; still further off, 85 miles from the bank, one of the German cruisers obtained 1566 fathoms. No soundings exist further from the bank in this direction.

These soundings may be the continuation of the Amirante Group to the northward, or of the Seychelles to the north-westward, but regarding the two groups as twin peaks of a single mountain chain, the approaches on the north-western side appear to be considerably less steep than on the other sides. This suggests that the Seychelles-Mauritius Plateau is continued in a modified form for at least a short distance to the north-westward before merging into the general depths of the ocean.

The remainder of the soundings obtained between Mafia and the Seychelles did not show any very marked irregularities ; the most prominent were two banks situated about 200 miles to the north-westward of Wizard Reef. These banks, rising 300 and 400 fathoms from the surrounding depths of 2650 fathoms, might be the last of the ridge on which Wizard Reef and the Farquhar Islands are situated.

The western basin therefore appears as generally deeper than the eastern, and sub-divided probably into two further basins, the deep water of one being connected to the southward on the western side of the Seychelles-Mauritius Plateau and of the other on the eastern side with the deep water of the Indian Ocean.

VI. AFRICAN COAST IN THE VICINITY OF MOMBASA AND ZANZIBAR. (Chart 4, and Pl. V.)

The coast between latitudes 3° and 9° S. lies in the form of a gently curving bay about 350 miles long and 70 miles deep. The bay contains Latham Island and the islands of Pemba, Zanzibar and Mafia. To the north of this bay the 1000 and 2000-fathom lines lie only about 27 and 100 miles respectively from the coast. Between the latitudes 3° to 9° S., however, these contours are about 100 and 210 miles from the mainland. Below 9° south the 1000-fathom has again approached to within about 30 miles of the coast. The 2000-fathom line is not shown here, as shoaler water appears to run to the northwestward from the Comoro Islands. The Island of Pemba is separated from the mainland by depths of 500 fathoms in the southern end of the channel and 200-fathoms in the northern end. Latham Island is separated by somewhat similar depths from the mainland. These channels and the relative positions of the 1000- and 2000-fathom contours suggest that the bay was formed by subsidence.

The majority of the soundings obtained and the stations made were inside the islands, only a few lines of soundings being run to seaward. No very great irregularities were found; the ridges appeared to be undulating and of no great height, similar to the coastal hills. The bottom was most irregular off Malindi Point, and several depths of less than 100 fathoms were obtained to a distance of 5 miles outside the charted 100-fathom line. While making the northern end of Pemba from the 1000-fathom line the slope was very gradual until a sharp ridge about 1000 feet high was crossed. This ridge may be a continuation to the southward of the irregularities off Malindi Point. About 40 miles to the eastward of this ridge a bank, slightly shoaler than the surrounding depths, also appears to be a continuation of the irregularities to the northward. Outside Latham Island the slope falls steeply into a channel running between Zanzibar and Pemba. On the outer side of this channel the bottom slopes gently upwards to a bank about 100 fathoms higher than the depth of the channel. On the western side of Latham Island a channel runs towards the 100-fathom line south of Zanzibar. With the exception of the soundings taken at the extreme northern end of this area, the slope below 200 fathoms appears to be extremely gradual.

Inside Pemba Island soundings were obtained showing the slope approaching the island and as necessary for stations. Soundings were also taken in order to verify, if possible, the existence of the 16-fathom sounding charted outside the 100-fathom line off Chaki Chaki Bay. No indications were found, the slope appearing quite normal.

VII. MALDIVE ISLANDS, CHAGOS AND CEYLON. (Chart 5, and Pl. VI.)

The soundings obtained by "Mabahiss" in this vicinity were mainly in Kardiva Channel and its approaches from the westward. In addition, soundings were taken from Colombo towards the Chagos Archipelago, thence northwards between the Atolls to Kardiva Channel. Lines of soundings were also run from Minikoi to Colombo and from Mâle to Colombo. Echo soundings taken by a German cruiser between Minikoi and Colombo and Suvadiva Atoll and Colombo were also plotted. From these soundings and those already charted the contours were drawn. The approaches from the westward appear to be quite uniform, and the fathom lines shown probably give a good idea of the slope on this side. On the eastern side and to the south, between Addu and the Chagos,

many irregularities exist, and until many more soundings have been obtained the contours cannot be drawn with any degree of accuracy. A sounding of 296 fathoms to the eastward of Tiladummati is shown in the Bathymetrical Chart published by the Prince of Monaco. Its origin could not be traced and it has been deleted.

In general, the Maldives, Minikoi and the Laccadives appear to be situated on one main ridge, the main ridge being considered as that mass of land which rises above the 1300-fathom line. From 8° N. this ridge runs slightly east of south, is regular in shape and has a fairly uniform width of 80 miles, the slope being steepest on the western side and falling to depths greater than 2000 fathoms. On the eastern side the water deepens to about 1500 fathoms.

From Ihavandiffulu to Kolumadulu the atolls situated on this central mass are all joined below the 700-fathom line, but Mabunudu may be an exception. Above the 1300-fathom line the contours become irregular in shape. At the 300-fathom line, the great majority of the atolls remain connected in a large central group with a small group and two isolated atolls detached. The small group consists of the atolls of Ihavandiffulu and Tiladummati-Miladummadulu, the two isolated atolls being Mabunudu and Fadiffolu, the remaining Atolls from N. Malosmadulu to Kolumadulu being attached to one another.

To the north the Island of Minikoi, Investigator Bank and the Laccadives are all probably connected with the central mass at depths greater than 1000 fathoms. The contours, however, are extremely irregular, and it is these irregularities in slope and contour in the vicinity of Minikoi that lead one to associate Minikoi with the Laccadives rather than with the Maldives.

To the south soundings obtained by "Mabahiss" and one of the German cruisers suggest that the southern atolls of Haddummati, Suvadiva, Addu and the Island of Fua Mulaku are also connected at depths less than 700 fathoms. These atolls may also be connected with the central mass below the 1000-fathom line. This southern mass differs from the others in that its eastern slopes fall to depths as great as those on its western side.

While these three masses are connected, they seem to have the appearance of overlapping, the contours of the northerly one running to the south and then turning south-east along the direction of Investigator Bank towards a sounding of 1159 fathoms in depths of over 1500 fathoms. The central mass commences slightly to the west of the northern one, runs to the southward, the contours then turning towards the south-east, where "Mabahiss" obtained 1709 and 1754 fathoms in depths of about 2200 fathoms (see Chart 3). Similarly the contours of the southern one run south and then appear to swing towards the south-east, where a sounding of 1298 fathoms lies in depths of about 1600 fathoms.

Addu to Kolumadulu.

A line of soundings was run to the eastward from the north-east corner of Addu, at which point the pendulum observations were taken. In this direction the 1000-fathom line was reached 4½ miles from the reef. To the north-east of the atoll the 1000-fathom line lay about 5 miles off. Between these two soundings a ridge rising to 590 fathoms was crossed, and shortly after the second crossing of the 1000-fathom line, another ridge of 654 fathoms was sounded over. If these two are continuous, it suggests a ridge running

to the south from Suvadiva towards Addu and branching off towards the south-east. On the other hand the first of these ridges may be a connection between Addu and Fua Mulaku. From this position onwards the depths deepened uniformly towards the 2000-fathom line.

A line of echo soundings between Haddummati and Suvadiva by one of the German cruisers revealed a depth of 38 fathoms lying midway between the two atolls. To the east and westward of this sounding lie other depths of about 1000 fathoms. The existence of this sounding suggests a submerged connection between the two atolls, or possibly a submerged atoll or reef. It must be remarked that this depth is an exceptional one for the open sea in the Maldives; no other such soundings are charted except in the lagoon entrances.

Off Kolumadulu a section of the slope on the south-eastern side of the atoll was taken, the 1000-fathom line being reached at a distance similar to that off Addu. The few existing soundings between Kolumadulu and Haddummati do not suggest a connection between them above the 1000-fathom line, but such may exist on the eastern side of the channel.

Kolumadulu to Kardiva.

Soundings were taken on the eastern side of the channel that runs north between the atolls. Once the channel was entered, the depths were practically constant at slightly over 200 fathoms. A comparison between these soundings and those already charted show the channel to be slightly deeper on its eastern than on its western side. It is noticeable in those groups of atolls connected by the 300-fathom line that the channels between them running north and south contain water of about 200 fathoms depth, while those running east and west have 270 fathoms. This difference is presumably accounted for by the scour of the currents which run east and west.

Kardiva Channel. (Chart 6.)

The majority of the soundings taken in the Maldives were obtained in Kardiva Channel during that period for which Major Glennie and Lieut.-Comdr. Farquharson were detached for pendulum and magnetic observations. The general depth in the channel is about 270 fathoms. The exceptions to this depth in the eastern end of the channel are in the vicinity of Fadiffolu and Kardiva, Fadiffolu Atoll being surrounded on its inner sides by a trough 400 to 500 fathoms deep. A similar trough, though probably not quite so deep, exists on the inner sides of Kardiva. To the northward of Kardiva Island the depths rose abruptly from over 400 fathoms to a plateau of 160 fathoms before dropping again to the trough lying to the southward of Fadiffolu. The existence of these troughs makes it unlikely that this plateau is directly connected with either Fadiffolu or Kardiva. More probably, the ship passed over the extreme western edge of a bank similar to, but deeper than, the bank to the south of Horsburgh.

On the eastern side of South Malosmadulu the depths are over 300 fathoms, but this trough is not continuous with that on the western side of Fadiffolu, as a steep ridge rising to 244 fathoms divides them.

On the western side of Kardiva Channel, to the north and immediately to the south of Horsburgh, the depths are typical of the channel. Further to the south lie King Fuad Bank, Toddu Island and Rasdu, these possibly all being detached portions of Ari Atoll.

The depths separating these three range from 140 to 166 fathoms, soundings more usual to the western side of the channel running north and south between the atolls than to a channel running east and west. It may be that the projection of Mále Atoll to the northwards shields these atolls from the scour of the west-going current.

King Fuad Bank, so named by permission of His Majesty the King of Egypt, has the appearance of being a sunken atoll. The Bank has the ordinary characteristics of an atoll, having generally a clearly defined rim about 40 feet high. The depth of the level floor inside is 130 fathoms. On the western side the slope rises steeply from the 1000-fathom line as the bank is approached.

A section of the slope from the west side of South Malosmadulu was run out to the 1000-fathom line. The three sections run in the Maldives are all similar in appearance. The depth increased rapidly to 200 fathoms, then less steeply to 400 fathoms. At 400 fathoms the slope steepened again down to 800 fathoms, where it tended to flatten out before dropping again to 1000 fathoms and more.

Minikoi and Investigator Bank.

Soundings taken while steaming to the eastward from Minikoi deepened to 1200 fathoms when about 7 miles from the island. Shortly afterwards they became irregular, rising to depths of a little over 900 fathoms. These irregularities persisted for a distance of about 30 miles, when the water deepened rapidly to over 1400 fathoms. This bank would appear to be a continuation of Investigator Bank to the south-eastward. In the same direction, but about 57 miles further out, a sounding of 1159 fathoms was obtained by one of the German cruisers in a general depth of over 1500 fathoms. It is possible that this is also situated on the same bank.

Soundings to the Eastward of the Maldives.

The soundings obtained by "Mabahiss" on passage from Mále towards Colombo deepened rapidly to 1200 fathoms after leaving the atoll and then gradually to depths of over 1400 fathoms. When 80 miles from Mále, they then shoaled slowly to depths between 1130 and 1150 fathoms. This shelving bank is about 65 miles in width and is divided by a trough of slightly greater depth. The bank appears to be a continuation southward from Cape Comorin of the mainland, and runs in a direction nearly parallel to the Maldive Ridge. A sounding of 1709 fathoms rising from 2200 fathoms obtained on a later cruise suggests that this bank may turn towards the south-east about latitude 3° N. However, this sounding was the peak of a ridge only about 10 miles in width. In contrast with the deep water immediately to the southward of Ceylon, the 2000-fathom line is not met with south of Cape Comorin until 270 miles from the mainland. Between the northern part of the Maldives and the 1000-fathom line off the Indian Coast, lies a basin of water between 1500 and 1640 fathoms deep. It does not appear that this basin has any connection with water of similar depth to the south-eastward.

To the eastward of the Cape Comorin Bank another arm of the bank runs in a south-eastern direction. This part of the bank has a gradual slope, and rises to a depth of 1554 fathoms from depths of 2200 with a width of about 100 miles. Between this arm and Ceylon a deep trough runs up into the Gulf of Manár. In the centre of this trough a shoal of 34 fathoms was reported in 1924. A line of soundings by "Mabahiss" passes

close to its reported position, but gives no indication of its existence. However, about 30 miles to the north-westward of this position a sounding of 1288 fathoms was obtained, rising from 1800 fathoms, which is the general depth of the trough in this vicinity. This is evidence that a ridge does lie in the trough, but that it rises to such heights as 34 fathoms seems improbable.

Whilst on passage from Minikoi to Colombo, soundings were taken on Wadge Bank, south of Cape Comorin, to obtain, if possible, indications of the 5-fathom patch reported on the bank. The least water obtained was 32 fathoms, and the bank appears to shelve gently and is not much in contrast with the surrounding depths.

Colombo to Chagos.

After the 2000-fathom line in about 3° N. was crossed the water deepened to a little over 2200 fathoms, until two ridges of 1709 and 1750 fathoms respectively, in latitude 2° N., were crossed; after this the water gradually deepened to 2500 fathoms about 110 miles to the eastward of Addu.

Chagos to Addu.

Soundings were obtained with difficulty and not continuously in this area, owing to the cylinder of the echo-sounding machine being fractured. The spare transmitter was shipped whilst making a station in the centre of the channel.

From the depth of 2500 fathoms the soundings shoaled rapidly to a little over 1600 fathoms, and became irregular. Two ridges rising from this depth were crossed, one of 1298 fathoms situated 82 miles to the south-eastward from Addu, and the other of 1383 fathoms 115 miles to the southward of the atoll. From the latter ridge the depths increased towards midchannel, where they were just under 2000 fathoms, decreasing again towards Chagos.

Enough soundings have not been obtained in the channel to show that no ridge connects the Maldives and the Chagos. The sounding of 1196 fathoms obtained by a German cruiser to the north of Speaker Bank suggests that less water may exist to the westward of the soundings obtained by "Mabahiss". It seems probable, however, that a trough of about 2000 fathoms connects water of this depth on the western side to that on the eastern.

It is noticeable that to the westward of the Maldives the tendency of the contours is to run towards the south-west, turning towards a little west of south. On the eastern side the contours in the Indian Ocean run to the south and turn towards south-east.

VIII. APPENDIX: MAGNETIC OBSERVATIONS.

The magnetic observations taken in the atolls of Fadiffolu and South Malosmadulu in the Maldives were submitted to the Astronomer Royal for consideration. It is considered that, while the mean of the whole series will furnish valuable data for the correction of the existing charts of dip and horizontal force, the series is insufficient to give reliable information as to local disturbance in the magnetic field.

These observations were carried out in conjunction with Major Glennie's pendulum

observations. The gravity stations were situated, one on the eastern and one on the western extremes of Fadiffolu, the remainder in South Malosmadulu, on the eastern and western extremes, and two in the centre of the atoll.

Magnetic observations were taken at these stations, and four additional ones in South Malosmadulu, making eight in all in this atoll, which was the maximum that time permitted. The necessary transport was carried out by means of a native sailing craft. It was realized that the area of the two atolls was much too large a one to be covered in a time limit of ten days. For that reason half the observations were taken on the western side of Malosmadulu in order that one part of the area should be covered comparatively closely, as far as the selected positions for gravity observations and the exigencies of transport would allow.

However, the results show that in order to ascertain with any degree of certainty the local abnormalities and to eliminate personal and instrumental errors and diurnal variations, a considerably longer time should be allowed for a survey of this nature. The existence of fixed marks and a triangulation would enable the observer to obtain the deflections without the necessity of erecting the instrument in the sun to obtain true bearings. The value of P, which should be constant, was found to have a large range due to a certain extent to the setting of the magnets not being sufficiently accurate, and also to the large range in temperature. Some of the vibrations were obtained during a range from 28° C. about sunrise to about 55° C. two hours later when the sun was well up. The dip observations which were not liable to these errors did not suggest the existence of any marked disturbances.

Maldive Islands : Magnetic Observations, March–April, 1934.

The following observations are the observed values and are not corrected for diurnal variation.

Kew magnetometer, Dover 161. Dip circle, Dover 188.

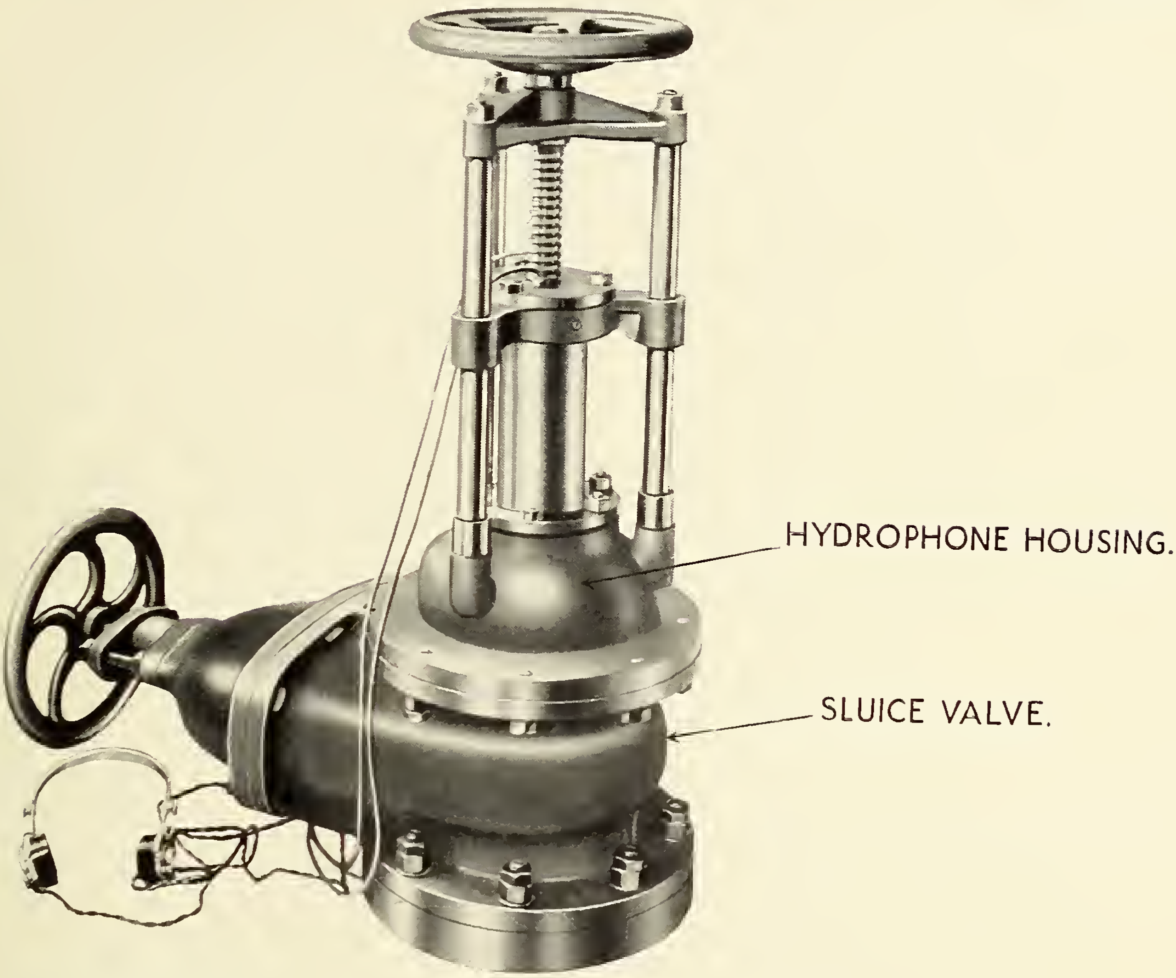
Place of observation.	Declination.		Inclination.			Horizontal force.		
	Date.	West.	Date.	Needle.	S.	Date.	By deflections.	By vibrations.
Difuri Island.	March 30.		March 30.			March 30.		
Fadiffolu.	12.00	3° 44′ 05″	09.00	No. 1.	6° 37·3′	15.00	0·38096	0·38100
5° 23′ 36″ N.	18.00	3° 42′ 30″	10.00	No. 2.	6° 32·9′	17.40		
73° 38′ 06″ E.	Mean	3° 43′ 18″	Mean		6° 35·1′			
Kanifuri Island.	April 1.		April 1.			April 1.		
Fadiffolu.	10.30	3° 32′ 10″	06.00	No. 1.	6° 00·6′	11.40	0·38029	0·38068
5° 22′ 12″ N.	15.00	3° 31′ 30″	06.45	No. 2.	5° 59·2′	14.00		
73° 19′ 12″ E.			16.00	No. 1.	6° 03·5′			
			16.45	No. 2.	6° 02·1′			
	Mean	3° 31′ 50″	Mean		6° 01·3′			
Fonimagudu.	April 2.		April 3.			April 2.		
Malosmadulu.	13.00	3° 33′ 49″	06.15	No. 1.	6° 44·9′	14.20	..	0·37884
5° 15′ 54″ N.	18.00	3° 37′ 22″	07.15	No. 2.	6° 37·6′	16.15		
73° 10′ 24″ E.	Mean	3° 35′ 35″	Mean		6° 41·3′			

Place of observation.	Declination.		Inclination.			Horizontal force.		
	Date.	West.	Date.	Needle.	S.	Date.	By deflections.	By vibrations.
Landa Girawa. Malosmadulu. 5° 18′ 00″ N. 73° 05′ 18″ E.	April 3. 11.30	4° 03′ 26″	April 3. 14.45	No. 1.	6° 38·1′	April 3. 12·00	0·38067	0·37994
	14.00	4° 02′ 59″	16.00	No. 2.	6° 37·4′	13.50		
	Mean	4° 03′ 13″	Mean		6° 37·8′			
Doomfano. Malosmadulu. 5° 12′ 21″ N. 73° 06′ 00″ E.	April 4. 09.30	4° 41′ 26″	April 4. 13.45	No. 1.	6° 55·9′	April 4. 10.10	0·37987	0·38057
	12.30	4° 41′ 21″	14.45	No. 2.	6° 54·2′	12.25		
	Mean	4° 41′ 23″	Mean		6° 55·0′			
Mamadu. Malosmadulu. 5° 13′ 30″ N. 73° 03′ 36″ E.	April 5. 10.00	3° 34′ 20″	April 5. 06.15	No. 1.	6° 49·6′	April 5. 09.15	0·38004	0·38002
	13.30	3° 35′ 56″	07.15	No. 2.	6° 49·2′	10.30		
	Mean	3° 35′ 08″	Mean		6° 49·4′			
Mandu. Malosmadulu. 5° 11′ 30″ N. 72° 58′ 00″ E.	April 6. 06.30	3° 35′ 20″	April 5. 17.00	No. 1.	6° 49·6′	April 6. 07.10	0·37903	0·37892
	09.30	3° 37′ 25″	17.45	No. 2.	6° 47·6′	10.00		
	Mean	3° 36′ 22″	Mean		6° 48·6′			
Megili. Malosmadulu. 5° 11′ 24″ N. 72° 55′ 06″ E.	..		April 6. 15.00	No. 1.	6° 46·3′	April 6. 12.30	0·37884	0·37831
			15.45	No. 2.	6° 52·0′	14.30		
			Mean		6° 49·2′			
Kanifuri. Malosmadulu. 5° 02′ 12″ N. 72° 55′ 15″ E.	April 7. 11.30	3° 44′ 56″	April 7. 16.00	No. 1.	7° 07·4′	April 7. 13.10	0·37919	0·37906
	14.00	3° 44′ 59″	17.00	No. 2.	7° 06·4′	15.30		
	Mean	3° 44′ 58″	Mean		7° 06·9′			
Toradu. Malosmadulu. 5° 02′ 42″ N. 72° 48′ 42″ E.	April 8. 13.00	3° 19′ 12″	April 8. 16.30	No. 1.	7° 03·2′	April 8. 13.10	0·37995	0·38091
	15.00	3° 20′ 12″	17.30	No. 2.	7° 02·2′	15.30		
	Mean	3° 19′ 42″	Mean		7° 02·7′			

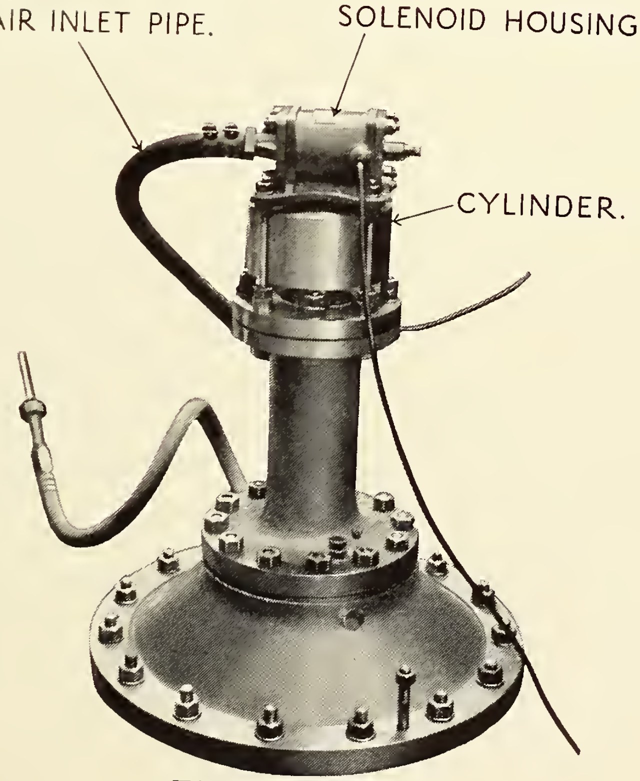
LIST OF CHARTS.

DESCRIPTION OF PLATE I.

Hydrophone (above) and Transmitter (below) of the Admiralty Recording Echo-Sounding Apparatus, Acadia type.



HYDROPHONE.

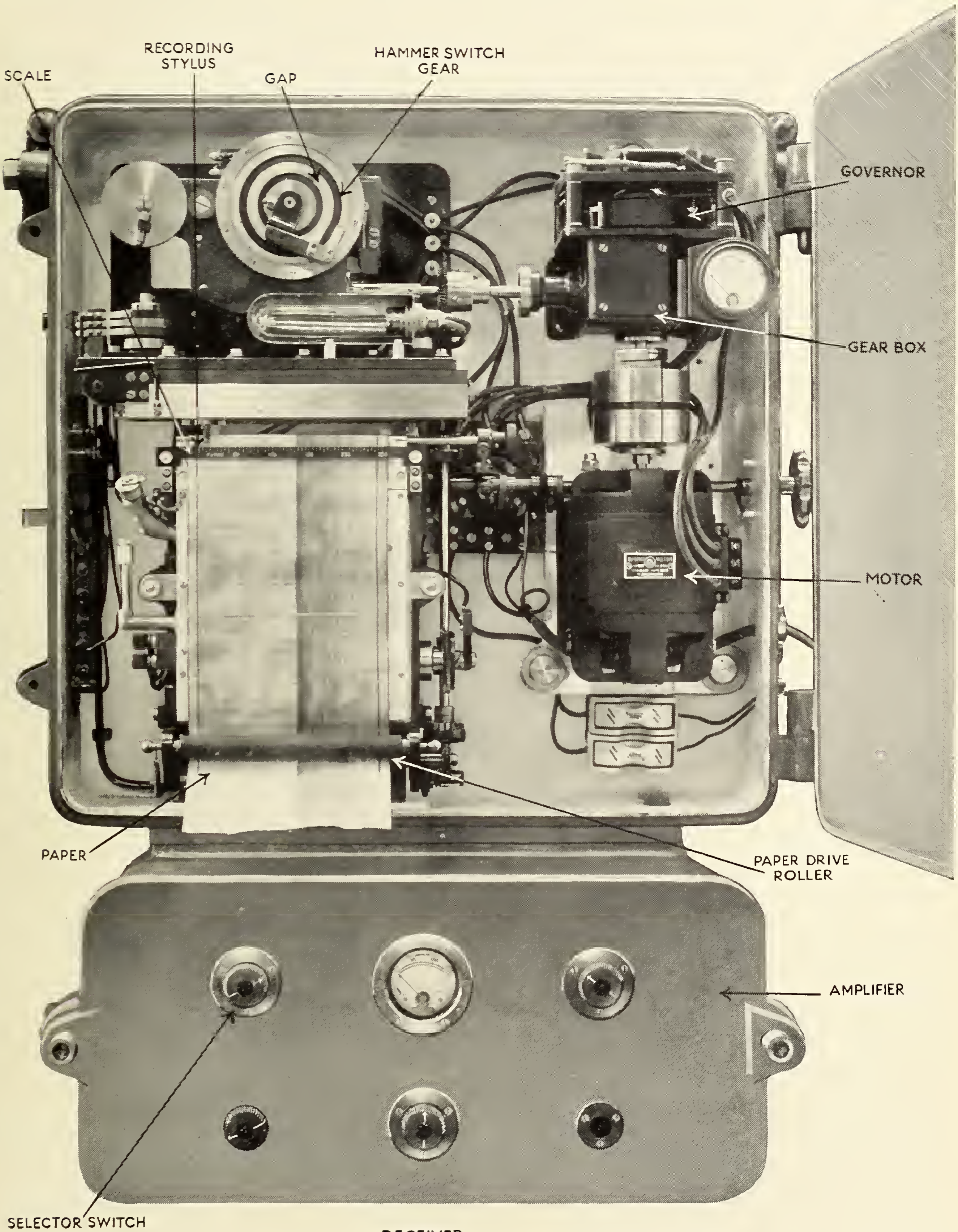


TRANSMITTER.

[*Adlard & Son, Ltd., Impr.*

DESCRIPTION OF PLATE II.

The Receiver of the Admiralty Recording Echo-Sounding Apparatus, Acadia type.



RECEIVER

[*Adlard & Son, Ltd., Impr.*

DESCRIPTION OF PLATE III.

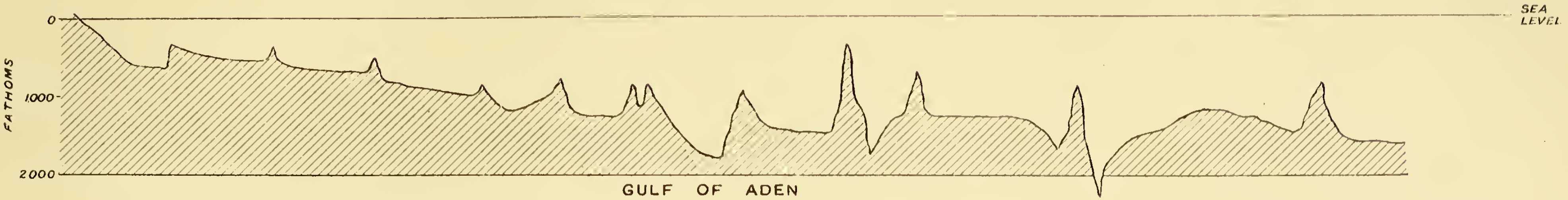
Sections in Gulf of Aden and Arabian Sea.

GULF OF ADEN

SECTION DOWN CENTRE OF GULF OF ADEN FROM OBOKH TO 13°30N. 54°00E.

VERTICAL SCALE ½" = {1000 FATHOMS OR 1 SEA MILE.

HORIZONTAL SCALE ½" = 38 SEA MILES.

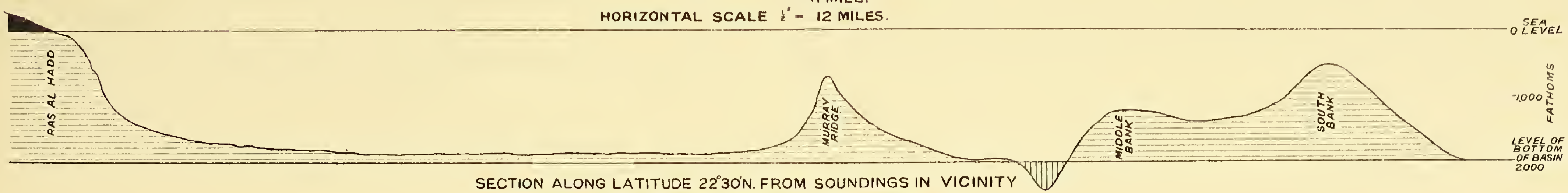


GULF OF ADEN

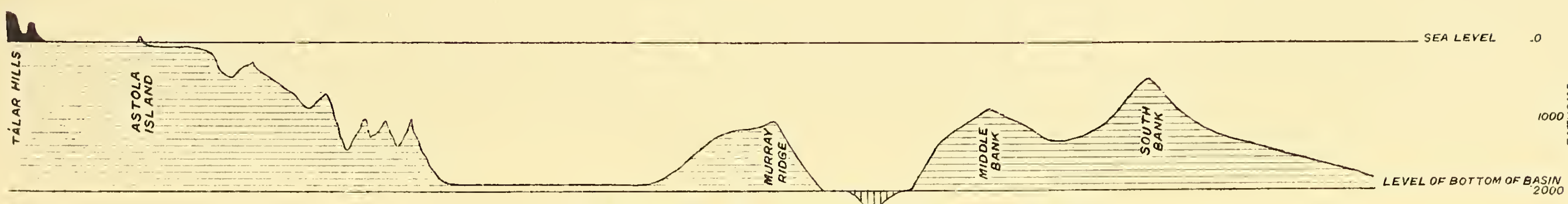
ARABIAN SEA

VERTICAL SCALE ½" = {1000 FATHOMS OR 1 MILE.

HORIZONTAL SCALE ½' = 12 MILES.



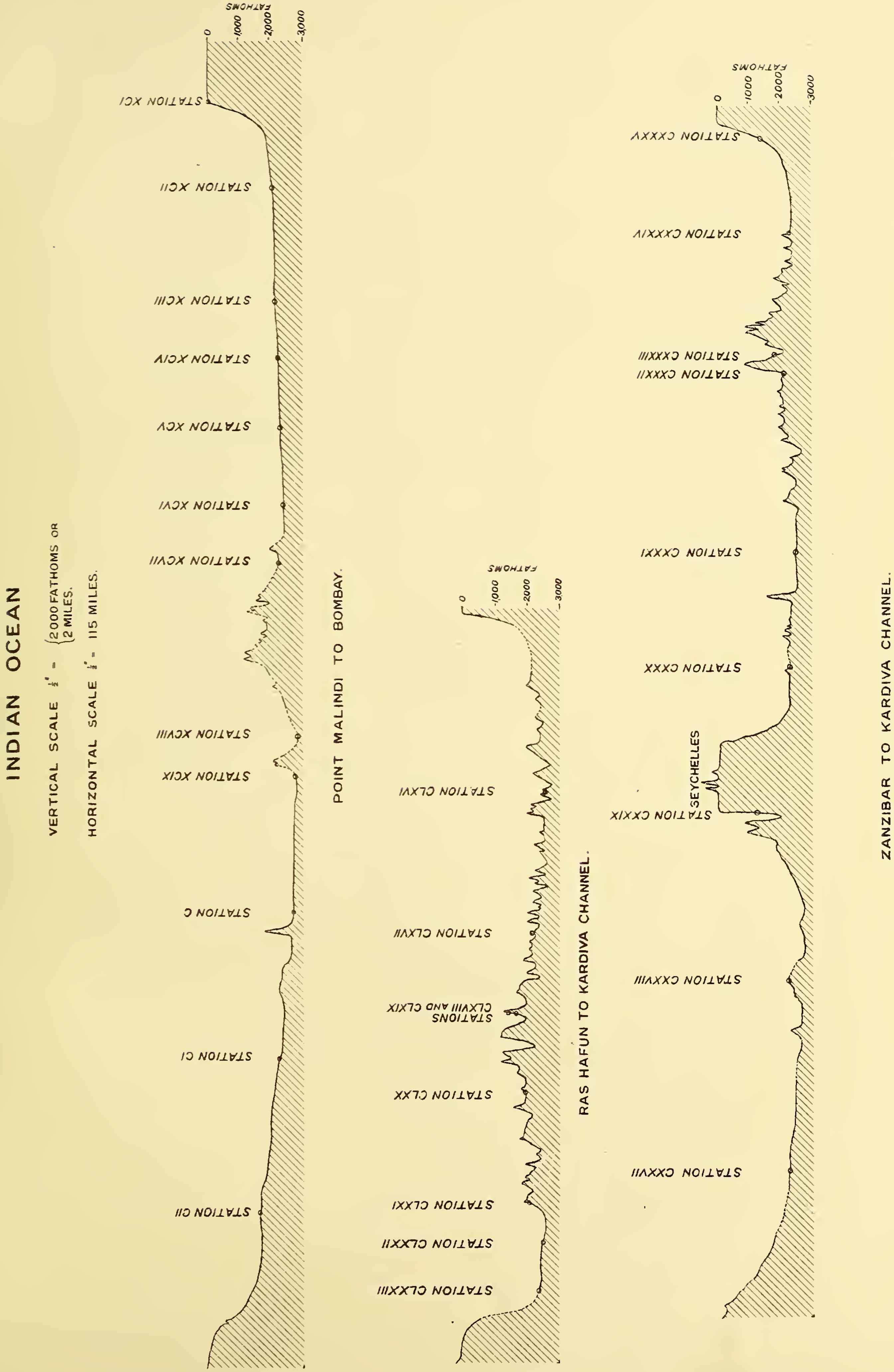
SECTION ALONG LATITUDE 22°30'N. FROM SOUNDINGS IN VICINITY
MAKRAN COAST AND ENTRANCE TO PERSIAN GULF.



MAKRAN AND ENTRANCE TO PERSIAN GULF
SECTION DRAWN ALONG 64TH MERIDIAN FROM SOUNDINGS IN VICINITY.

DESCRIPTION OF PLATE IV.

Sections in Indian Ocean.


INDIAN OCEAN
VERTICAL SCALE 1/2" = {2000 FATHOMS OR 2 MILES.
HORIZONTAL SCALE 1/2" = 115 MILES.
POINT MALINDI TO BOMBAY.
RAS HAFUN TO KARDIVA CHANNEL.
ZANZIBAR TO KARDIVA CHANNEL.
FATHOMS
0
1000
2000
3000
STATION XCI
STATION XCII
STATION XCIII
STATION XCIV
STATION XCV
STATION XCVI
STATION XCVII
STATION XCVIII
STATION XCIX
STATION C
STATION CI
STATION CII
STATION CLXVI
STATION CLXVII
STATIONS CLXVIII AND CLXIX
STATION CLXX
STATION CLXXI
STATION CLXXII
STATION CLXXIII
STATION CXXXV
STATION CXXXIV
STATION CXXXIII
STATION CXXXII
STATION CXXXI
STATION CXXX
SEYCHELLES
STATION CXXIX
STATION CXXVIII
STATION CXXVII

DESCRIPTION OF PLATE V.

Sections off Zanzibar and Pemba.

ZANZIBAR AND PEMBA

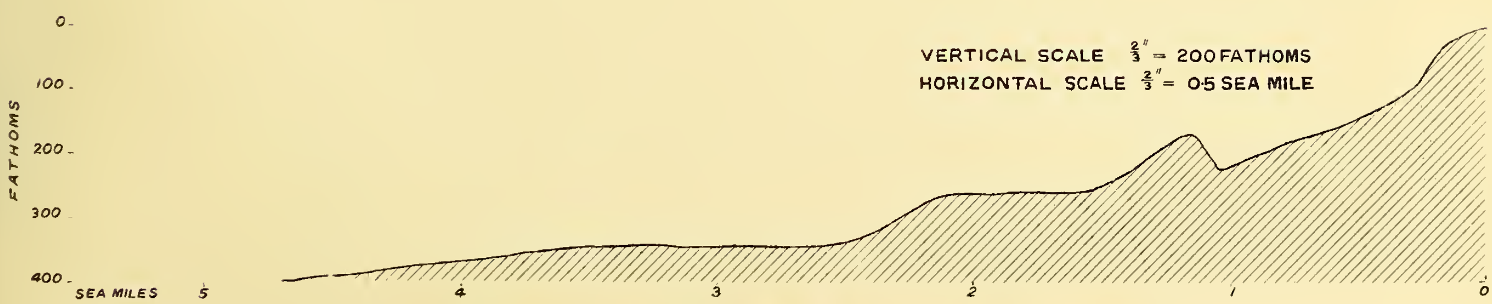
VERTICAL SCALE $\frac{2}{3}''$ = 500 FATHOMS.
HORIZONTAL SCALE $\frac{2}{3}''$ = 5 SEA MILES

SLOPE TO SEAWARD FROM SOUTHERN POINT OF ZANZIBAR.

VERTICAL SCALE $\frac{2}{3}''$ = 500 FATHOMS.
HORIZONTAL SCALE $\frac{2}{3}''$ = 5 SEA MILES.

SLOPE TO SEAWARD FROM 100 FATHOM LINE NORTH OF PEMBA.

VERTICAL SCALE $\frac{2}{3}''$ = 200 FATHOMS
HORIZONTAL SCALE $\frac{2}{3}''$ = 0·5 SEA MILE



SLOPE ON WESTERN SIDE OF PEMBA: EAST SIDE PEMBA CHANNEL.

DESCRIPTION OF PLATE VI.

Sections off Maldive Islands.

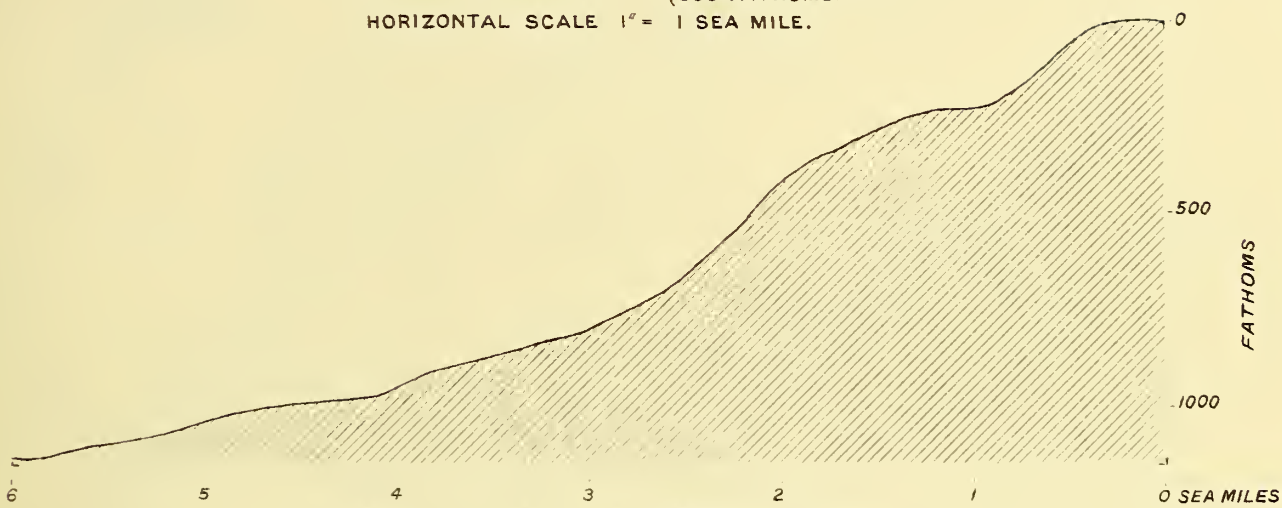
Brit. Mus. (Nat. Hist.)

MALDIVES

Plate VI.

VERTICAL SCALE 1" = {0·5 SEA MILES OR 500 FATHOMS.

HORIZONTAL SCALE 1" = 1 SEA MILE.



SLOPE TO WESTWARD OF MALOSMADULU ATOLL.

SLOPE TO EASTWARD MIDU ISLAND.

SLOPE TO EASTWARD OF KOLUMADULU ATOLL

JOHN MURRAY EXPEDITION, 1933-34.

REPORTS, VOL. I. Nº 2.

GULF OF ADEN

SOUNDINGS IN FATHOMS

BRIT. MUS. (NAT. HIST.)

CHART I.

JOHN MURRAY EXPEDITION, 1933-34.

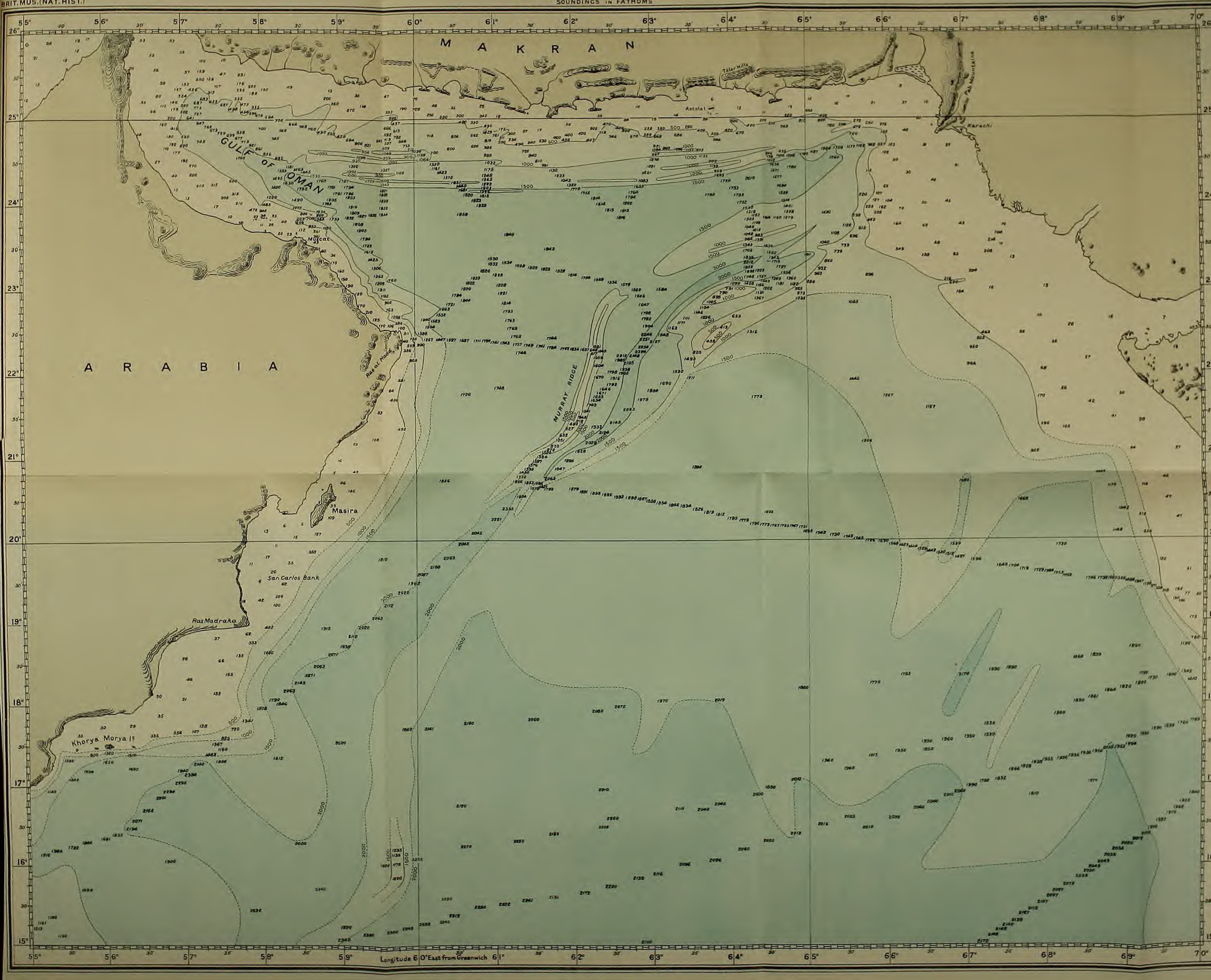
REPORTS, VOL. I. No 2.

BRIT. MUS. (NAT. HIST.)

ARABIAN SEA

SOUNDINGS IN FATHOMS

CHART 2.



JOHN MURRAY EXPEDITION, 1933-34.

REPORTS. VOL. I. No. 2.

INDIAN OCEAN

SOUNDINGS IN FATHOMS

BRIT. MUS. (NAT. HIST.)

CHART 3.

JOHN MURRAY EXPEDITION, 1933-34.

REPORTS. VOL. I. Nº 2.

MOMBASA AND ZANZIBAR

SOUNDINGS IN FATHOMS

CHART 4.

JOHN MURRAY EXPEDITION, 1933-34.

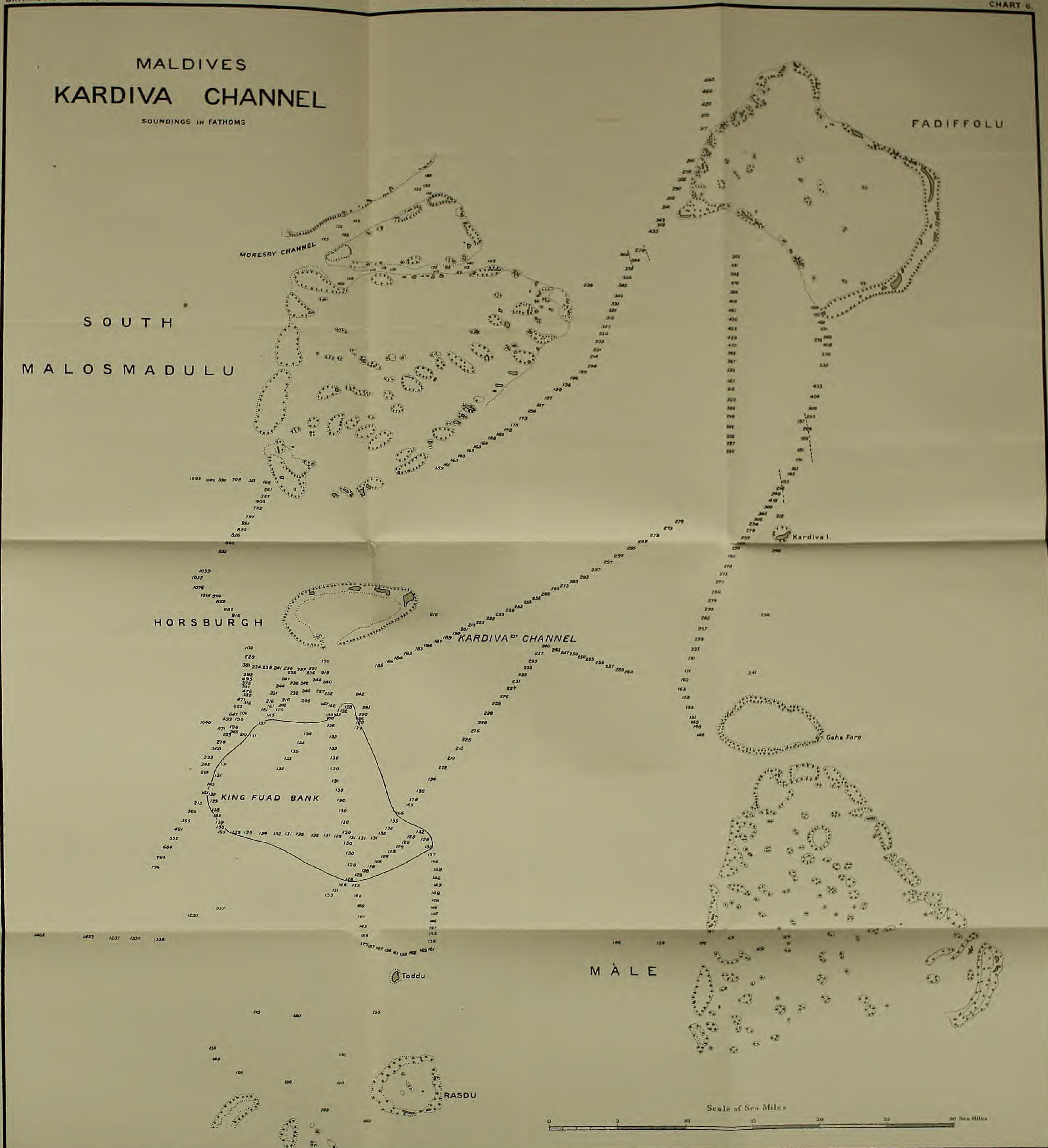
REPORTS, VOL. I. No. 2.

BRIT. MUS. (NAT. HIST.)

MALDIVES

SOUNDINGS IN FATHOMS

CHART 5.


MALDIVES
KARDIVA CHANNEL
SOUNDINGS IN FATHOMS
FADIFFOLU
MORESBY CHANNEL
SOUTH
MALOSMADULU
HORSBURGH
KARDIVA CHANNEL
Kardiva I.
KING FUAD BANK
Gaha Faro
Toddu
MÀLE
RASDU
Scale of Sea Miles
0
5
10
15
20
25
30 Sea Miles

BRITISH MUSEUM (NATURAL HISTORY)

THE

JOHN MURRAY EXPEDITION 1933–34

SCIENTIFIC REPORTS

VOLUME I. No. 3

AN ACCOUNT OF ADDU ATOLL

BY

R. B. SEYMOUR SEWELL, C.I.E., Sc.D., F.R.S.
(Lieut.-Colonel, I.M.S. (ret.).)

WITH EIGHT PLATES AND ONE TEXT-FIGURE

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R. B. SEYMOUR SEWELL, C.I.E., Sc.D., F.R.S.
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WITH EIGHT PLATES AND ONE TEXT-FIGURE

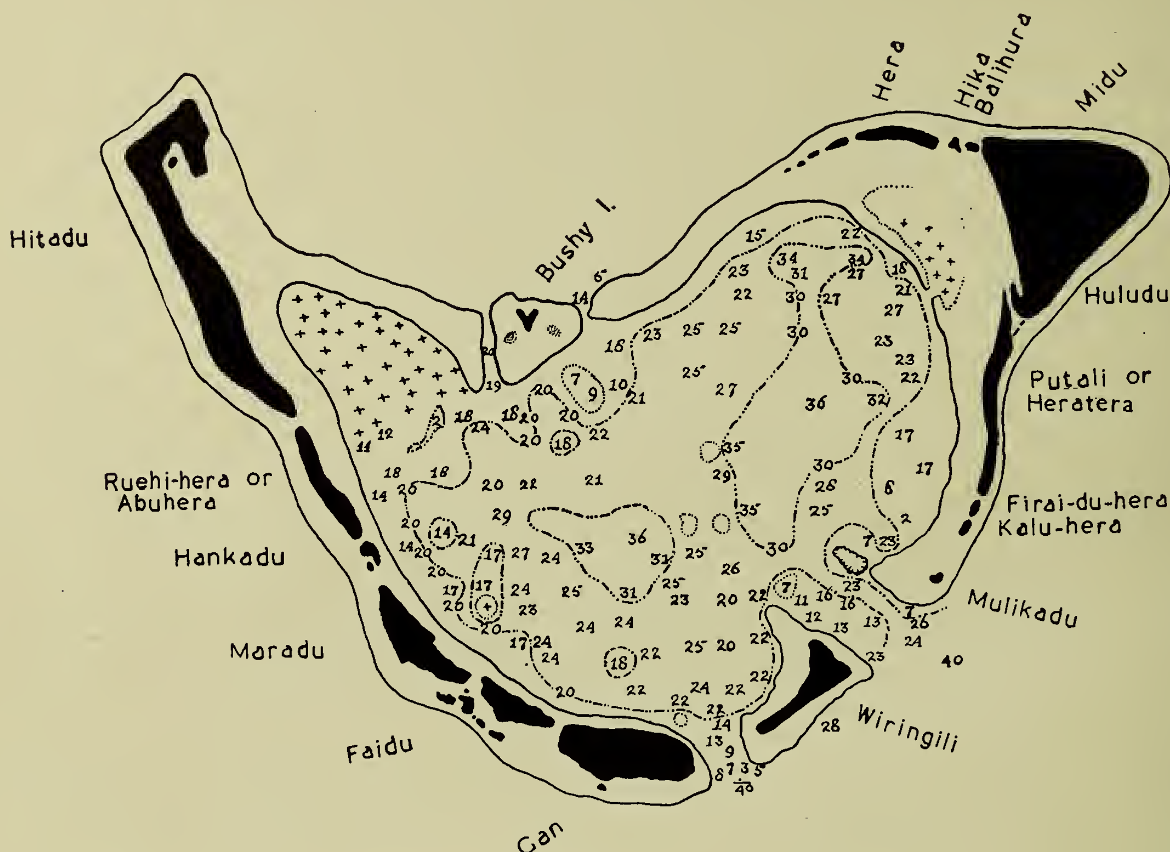
Addu Atoll is the most southerly atoll of the Maldive Archipelago, and is situated in lat. 0° 36′ 30″ S., long. 73° 09′ 30″ E. It occupies a position at the extreme south end of the archipelago very similar to that which Minikoi occupies at the north ; both arise as completely isolated atolls from a depth of some 900–1000 fathoms.

Addu atoll was first surveyed by Moresby in 1836, and since then it has been visited by Stanley Gardiner and Forster Cooper in 1900, and by Agassiz in 1902. Both Stanley Gardiner and Agassiz have given more or less detailed accounts of the atoll and have compared their results with Moresby's original chart ; it may therefore be thought that any further account of the atoll is unnecessary, but my excuse is that after a lapse of some thirty years a further re-study of the same area has a special interest, in that it enables one to note the changes that have taken place in the meantime.

Agassiz (1903, p. 145) has described the atoll as being triangular in shape ; it is, however, more nearly correct to call it crescentic, and Agassiz himself called attention to the two horns that jut out at the north-east and north-west ends of the atoll. The two borders of the crescent exhibit marked differences. At the two horns and scattered along the southern border are numerous islands, three of which, namely Midu-Huludu at the extreme eastern horn, Hitadu at the western horn, and Gan, just where the curved rim reaches its most southerly point, are considerably larger than the others. The concave northern border of the crescent presents a marked contrast to the southern rim, in that it is formed by an almost bare reef, on which only a few small islands and " sand-cays " are situated. Both the northern and southern rims are broken about the middle of their length, and in each case a small central portion of the reef is isolated by deep channels that connect the lagoon with the surrounding ocean.

To what extent the shape of the atoll is attributable to the configuration of the mountain peak on which the atoll is situated on the one hand, and the different rates of growth of the reef itself, under the influence of surface currents, etc., it is at present impossible to decide. The presence of the coral island Fua-Mulaku to the north-east of Addu atoll suggests that the basic mass on which the atoll is perched extends considerably towards the north-east, and in this connection it is interesting to note that Farquharson, in his account of the topography of this region (1936, p. 56), remarks that " soundings obtained by " Mabahiss " and one of the German cruisers suggest that the southern atolls

of Haddumatti, Suvadiva, Addu and the Island of Fua-Mulaku are also connected at depths less than 700 fathoms. These atolls may also be connected with the central mass below the 1000 fathom line. This southern mass differs from the others (to the north) in that its eastern slopes fall to depths as great as those on its western side ". To the eastern and north-eastern side of Addu atoll the seaward slope is very gradual, the 50-fathom contour not being reached till some three-quarters of a mile from the reef edge ; at this point there is a sharp increase in the angle of the slope down to about 200 fathoms, and then comes a more gradual slope down to 250 fathoms, followed again by a steep slope to nearly 400 fathoms. Beyond this, at a distance of about $1\frac{1}{3}$ miles from the reef edge,



Text-fig. 1.

the character of the slope changes and now shows a tendency to become convex, falling slowly to 750 fathoms, which is reached at about $2\frac{1}{3}$ miles from the reef. Further seaward the slope again becomes very gradual, so that between $2\frac{1}{2}$ and $3\frac{1}{2}$ miles out the depth increases by only some 100 fathoms ; soon after the $3\frac{1}{2}$-mile distance is reached the bottom again drops, and the 1000-fathom level is reached in another $\frac{3}{4}$ mile (Chart 5). According to the contours drawn by Farquharson, there are indications of a Y-shaped ridge running out from the atoll in an easterly direction, the northern bifurcation of the Y turning in the direction of Fua-Mulaku. It would thus seem probable that there is a natural tendency for the submarine contours to extend towards the east and north-east, and this might account, at any rate in part, for the existence of the north-eastern horn of the atoll.

It is generally admitted that the usual effect of an ocean current, bringing with it

increased food-supplies for the coral polyps and their symbionts, will be to promote an increased rate of growth and a consequent extension of the reef in the direction from which the current is flowing : but at the same time one must not forget the fact, to which Darwin drew attention as long ago as 1842, that reefs exhibit a tendency to extend in the direction of the current that flows along them. Two distinct processes are in all probability at work, namely (1) the supply of nutriment leading to more active growth and hence to an extension of the reef, and (2) the distribution of the fragments broken off a reef, and the gradual building up of a talus slope on which the reef can extend. In the region of the Maldives the surface currents exhibit great changes at different seasons of the year and in different parts of the Archipelago. Agassiz (1903, p. 145) has drawn a comparison between Minikoi and Addu atolls, and points out that the " climatic conditions under which they are placed are quite different. Minikoi is in the region of the north-east and south-west monsoons, while Addu is in the equatorial region of variable southerly and westerly winds, with rain squalls prevailing ". The latter part of this statement hardly agrees with my experience. During January and February and the first half of March the wind is usually from the north-east, and blows with a force of 2–3 Beaufort scale ; Stanley Gardiner (1903, pp. 20–21) found that the north-east monsoon was felt in Addu from " January to March, but the wind is here very irregular, veering at any time six points on either side of north-east ". During the transitional period between the north-east and south-west monsoons the winds experienced are very variable, but on the whole exhibit a tendency to blow from the north-west. Forster Cooper (*vide* Stanley Gardiner, 1903, p. 26) was in this region in the months of March and April, 1900, and in his notes he states, " in my journey through the atolls of South Mále, Felidu, Mulaku, Kolumadulu and Haddummati I experienced only north-westerly winds with the exception of an easterly gale, lasting three days, while I was in the south of Felidu atoll ". In the latter part of March and early April, 1934, we found that in this area the wind was variable, but in the main blew from the north-west or west-north-west with a force 3, rising at times to force 4 Beaufort scale. It is probable that the strength and persistence of north-westerly winds varies considerably in different years and at different seasons of the year. The 'West Coast of India Pilot' (1919, p. 348) states that in Equatorial Channel, which separates Addu and Suvadiva atolls, " in September the north-west monsoon (which prevails for nearly all the first half of the year from the Equator to Chagos Archipelago, commences with about a fortnight's hard squalls and fresh gales from the West to W.N.W.", and this must also be felt to some and possibly to a considerable extent at Addu.

It is also during this season of the year, or during the corresponding change from the south-west to the north-east monsoons in September–October, that cyclones are most likely to arise in the Laccadive Sea ; as Oldham (1895, p. 12) has pointed out, " Hurricanes (cyclones) are rare at the Laccadives, but between these islands and the coast of India and to the south-eastward over the southern end of the Indian Peninsula hurricanes are comparatively frequent. Their course is to the W.N.W. or north-westward, passing up between the Laccadives and the Malabar coast ". Such storms will give rise to gales and heavy seas from the north-west or west in Addu atoll ; and it seems probable that these north-westerly winds are responsible for several features both in the rim of the atoll and in some of the islands on the reef-platform. As Murray (1913, p. 69) remarks, " in the Indian Ocean a comparatively low surface temperature prevails over the north-western portion of the Arabian Sea, brought about by the prevailing north-westerly

winds driving the warm surface water to the south-eastward and thus by upwelling off Cape Gardafui bringing the colder waters of the lower depths nearer to the surface ". This effect of the north-westerly winds will be to produce a surface current that will impinge on Addu atoll at the north-west corner and, by bringing increased food-supplies, should be favourable to the growth of coral and the consequent extension of the reef at this point. Similarly the effect of the north-east monsoon wind, combined with the north Equatorial Current, would be favourable to growth and extension of the reef in that direction. Stanley Gardiner (1903, p. 416) concludes from the observations taken by himself and Forster Cooper that " the chief points to seaward (in the contour of the atoll) are all more emphasized and prominent at the present day than shown in his (Moresby's) chart ", and again (*loc. cit.*, p. 151) he remarks that " the seaward edge of the reef, particularly round the semicircle to the south and at the two horns (north-east and north-west), has grown considerably outwards ". A comparison of the charts given by Moresby and Stanley Gardiner with the condition at the present day would appear to indicate that there has been a very great outgrowth at the two horns, and especially to the north-west. My own observations lead me to conclude that the north-western horn projects out from the main mass of the atoll even further than Stanley Gardiner has shown it, and I have indicated this in the chart. If we accept the accuracy of the previous charts one must conclude that the north-west horn has grown out approximately 1 mile between 1836 and 1900, and a further $\frac{1}{2}$ mile between 1900 and 1934, a rate of extension of 26·4 yards a year, or 2·2 yards a month ! One hesitates to bring an accusation of inaccuracy against a trained surveyor, such as Moresby, though when one considers the conditions under which his survey was made one is surprised that he attained results as accurate as he did ; but a comparison of the land contours of the island on the north-west horn, as shown in the various charts, clearly reveals such a degree of similarity that one is forced to conclude that there has been little or no change in this part of the atoll, and that the apparent outgrowth of the north-west corner is due to faulty charting ; but there seems to be no room for doubt that the north-east has extended outwards to some, and possibly to a considerable extent.

The other ocean current that might influence the rate of growth of the reef and, therefore, the shape of the atoll is that of the south-west monsoon. Situated as this atoll is to the south of the equator, it is out of the line of the full force of the south-west wind at this season of the year and, indeed, the ' West Coast of India Pilot ' states that " Addu atoll is almost beyond the influence of the south-west monsoon ". Stanley Gardiner (1903, p. 21) also states that in this atoll the south-west monsoon is not felt. This, in my opinion, is an over-statement ; there is a definite effect produced by this monsoon, though to a less extent than further to the north, and furthermore, the main direction of the wind at this season is from the west to west-south-west rather than strictly from the south-west, and this is in agreement with Stanley Gardiner's own experience, for he (1903, p. 21) records that he experienced " in the channels between Addu and Suvadiva and between the latter and Haddumati heavy gales from the west ".

Such a wind will produce a surface current that at first one might consider would be favourable to the growth of coral, but the onset of this westerly wind is often accompanied by heavy rain and a fall in the temperature of the water, so that the possibly beneficial effect of an increased food-supply may to some extent be counterbalanced, and there certainly seems to be little, if any, tendency for the reef to grow out towards the

south-west. Owing to the configuration of the atoll a south-westerly moving current, striking against the north-east corner, will tend to be diverted, part flowing southwards along the east face of the atoll and part passing along the north face, and so finally being diverted towards the north-west. Similarly a north-easterly moving current, impinging on the south-west side of the atoll, will be diverted towards the north ; and it is possible that this movement of the water during the two monsoons has had some influence in moulding the projection of the north-west horn.

I have already mentioned that both north and south sides of the atoll rim are interrupted by channels. The position of these openings is interesting ; it is generally stated and accepted that the channels out of the lagoons into the open sea are for the most part to be found on the lee-side of an atoll, the view being that they are kept open by the outflowing current of water that has been spilled over the windward reef by the breaking waves. In Addu atoll, owing to the alternating seasons, the lee-side will be the south-west side from November to January or February, during the period of the north-east monsoon, and the north-east and east sides will be the lee side during the period of the south-west monsoon from May to August. The effect of this alternation of the direction of the wind will be that these seasons tend to neutralize each other, so far as their effect on maintaining channels through the reef is concerned. In March, and again in September and October, the prevailing wind is from the north-west, and, moreover, it may blow from this quarter with considerable force, whereas it but rarely blows from the south-east. The effect of a strong north-westerly wind will be to pile up the water in the concavity of the northern reef, through the channels of which it will flow into the lagoon, and from thence it will in turn escape by the channels through the southern reef. It is interesting to note that the line passing through both sets of channels runs in a direction 30° west of north.

Of the four openings, those on the south side are the more important, as they are considerably wider than those in the northern rim. The south-western channel, between Wiringili and Gan Islands, is comparatively shallow, but the south-eastern one, between Wiringili and Mulikadu Islands, is deep, having 20 fathoms of water throughout the greater part of its length. In the neighbourhood of this latter channel the reef has grown inwards towards the centre of the lagoon for a considerable distance, thus prolonging the entrance channel, and on each side there is, in addition, a detached extension of the coral reef beyond the actual end of the lagoon reef, and separated from it by a depth of 10 fathoms or more. On the east side of the channel this detached area has grown up to the surface and is exposed at low tide : Stanley Gardiner (1903, p. 319) states that the patch to the north of the south-east passage, charted by Moresby in 1836, has become joined to the reef ; but in this he is mistaken. He figures it quite correctly as separate from the outer reef, and there was between them at the time of my visit a channel with a depth of water of over 10 fathoms. On the west side, beyond the point of the outer reef, lies the detached shoal that was discovered by Forster Cooper (*vide* Stanley Gardiner, 1903, p. 319), and beyond this again is another somewhat larger shoal that rises from 26 fathoms in the channel to 17 fathoms in the middle of the shoal.

In the channel of the south-west entrance there is no indication whatsoever of any tendency on the part of the reef to grow inwards towards the lagoon. This difference between the two openings is interesting, and is doubtless correlated with the different behaviour of the tidal currents in the two channels. During the flood tide a strong

current sets in through the south-east entrance and, simultaneously, an equally strong current sets out of the lagoon through the south-western channel ; on the ebb the current sets out from the lagoon through both channels ; thus, whereas in the eastern channel there is a reversal of the surface current with the change of the tide, in the west channel the current flows continuously out of the lagoon. The inward trend of the reef on the two sides of the deep eastern channel is probably correlated with this inward current, and the action of waves sufficiently powerful to detach fragments of coral from the reef and fling them inwards—a process that is clearly shown in these channels by the heaping-up of small islands on either side of the entrance ; the talus slope thus produced would be modelled by the inflowing current into spits running inwards on either side of the entrance. On the other hand, the view that these entrance channels are kept open by the action of the outflowing current, which brings with it silt from the lagoon and thus smothers the corals that otherwise might grow in the bed of the channel, is not borne out by the conditions present in this atoll, for clearly, if this were the true cause, then the western channel, through which the current at all times sets out from the lagoon, should be the deeper of the two, whereas, as we have just seen, the exact opposite is the case.

The two northern channels are narrower than the southern ones, and here again we find that one is rather deeper than the other. The western channel has a depth of 20 fathoms, while the eastern entrance possesses only 14 fathoms at its seaward end. The deep western channel, like the deep eastern channel on the southern side, shows an extension inwards into the lagoon of the reefs on its two sides, and here also there are several small shoals just inside the entrance. As on the south side, this difference is correlated with the different behaviour of the tides in the two entrances : through the western channel the tide sets into the lagoon on the flood and out from the lagoon on the ebb, but in the eastern channel the current runs out from the lagoon at all states of the tide. Stanley Gardiner stated (1903) that these northern channels were closing up owing to the growth of coral in them, and that, in consequence, they were no longer used by native craft ; in this, however, he seems to have been mistaken. Soundings taken by us in 1934 show that the depth of water at the present day agrees closely with what Moresby found in 1836, so that there has been little or no change in the period of 100 years. The explanation of Stanley Gardiner's mistake is probably to be found in the fact that he was in Addu atoll in the month of April, and that at this period of the year the prevailing wind is from the north-west. The most important fishing villages in the atoll are Midu and Huludu, and these are situated in the north-east corner of the lagoon. As the native boats are very bad at beating to windward, which would be necessary in order to leave the lagoon by the northern entrances, when the wind is in the north-west quarter, the fishermen leave the lagoon by running before the wind through the south-east entrance. On their return they land opposite the village on the outer reef, the boats being run in on the top of a wave and then rapidly pulled up the reef before the next wave breaks. They are subsequently pulled over the reef and through the channel between Huludu and Putali to the lagoon to be ready for the next day's fishing. In this way a long detour round into the lagoon is avoided and there is no necessity to use the northern channels. They, however, do so occasionally, and all dhows coming from the atolls to the north of Addu, during the time that I was in the atoll, entered the lagoon through one or other of the northern channels.

THE REEF PLATFORM.

A study of the reef platform shows that even in the same atoll there may be a very considerable variation in the width from sea face to lagoon margin. In Addu atoll the narrowest part of the reef platform is to be found on the northern side ; here the distance measured radially from the outer fissure zone to the inner lagoon reef is roughly 500 yards. On the east side of the atoll the width of the reef platform is about 1200 yards, while on the west and south-west sides it is as much as 1700–1800 yards. These differences seem sufficiently great to demonstrate that reefs may. even in the same atoll, vary enormously in width. but if we consider the distances between the lagoon reef and the reef face in the two horns, at the north-east and north-west corners, the difference is increased enormously. In the north-east area the distance from the lagoon reef to the reef face, measured radially, is as much as 4000 yards, while in the north-west part, where the island Hitadu projects outwards, it is as great as 6000 yards. so that at this point the width of the reef is at least ten times as great as it is along the northern side of the atoll.

THE OUTER REEF.

The outer part of the reef lying between the seaward face of the islands and the reef margin agrees very closely with the descriptions given by previous authors of the corresponding part of the reef in other atolls ; but there are certain differences in the character of the reef on the two sides of the atoll.

The edge of the reef is, as usual. composed almost entirely of nullipores, most of them being of a dull red colour, and it is cut into buttresses and deep channels, through which the water pours back off the reef after each succeeding wave. Even after the cessation of the north-east monsoon there is a heavy surf breaking on this part of the reef, and this renders a close inspection of its more detailed features impossible. The fissure-zone slopes slightly upwards to the seaward flat of the reef, but few, if any, of the fissures actually penetrate as far as the top of this slope, the reef crest (Pl. I, fig. 1).

Commencing at the eastern horn and following the outer or seaward flat to the south, to the east of Midu-Huludu Island the flat is comparatively wide and the outer edge, between the reef flat and the Buttress and fissure zone, is raised along its whole length about a foot above the general level of the flat. At the southern end of the island opposite the village of Huludu and between it and the next island to the south, Putali or Heratera, there is a wide bay, which is covered by a depth of about 9 in. of water at low-water spring tides except on the inshore side of some masses of rock on the flat, where the depth of water is deeper owing to scouring out of the floor to a depth of an additional foot or so. The floor of this bay is almost entirely covered by a bed of coral fragments and sand, the latter occurring in patches, and the whole is densely overgrown by a profuse crop of a red or green grass-like weed (*Cymodocea* ?). Commencing on or near the reef crest several spits of broken coral and small boulders run inwards across the flat towards the islands. From the south-east point of Huludu a line of coral rock, about 3 ft. in height, extends. like a broken wall from north to south across the bay (Pl. I, fig. 2, and Pl. II, fig. 1), and at its southern end merges into the piled-up masses of coral boulders on the sea face of the island of Putali. The rock of which this wall is composed consists of lumps of broken and water-worn coral, together with shell fragments, etc., embedded in a coarsely granular

matrix that resembles sandstone. The luxuriance of the growth of the weed on this flat is probably attributable to " manureing " by the inhabitants of the neighbouring fishing village, Huludu, and the flat possesses a rich fauna ; lying on the reef were several large black Holothurians and a number of examples of *Synapta*, while two or three eels of a species of *Murœna* were seen, as well as numerous small fish that were darting about in the weed and small crabs crawling over the coral fragments.

Stanley Gardiner remarks, " the presence of conglomerate masses I can only regard as indicating the existence of former land masses in any position ", an opinion with which I entirely agree; and it seems to me that we have in this ridge of rock stretching across the bay the still-persisting remains of the outer line of an old connection between Huludu and Putali, which has subsequently disappeared owing to erosion. On the south-west side of the bay at a little above high-water mark on the beach of Putali there is a small outcrop of a conglomerate rock, consisting of masses of coral, for the most part water-worn, shells, etc., and the varied position of the coral masses undoubtedly indicates that these have not been embedded *in situ* as they were growing, but have been piled up, some sideways, others upside-down, and have subsequently been consolidated. In the chart of the atoll given by Stanley Gardiner (1903, p. 415), which is based on the observations made by Capt. Moloney and Forster Cooper, a small crescentic island is shown lying to the outer side of the gap between Huludu and Putali, but at the present time the only indication of the former presence of any such island is the line of coral rock referred to above, and there is evidence on both the north and south sides of the bay that the sea is encroaching.

Between the two islands, Huludu and Putali, a channel runs from the outer reef to the lagoon. This channel runs at first westwards and then turns northwards for a short distance, after which it again bends to the west and then north, before finally turning sharply westward to enter the lagoon opposite the middle of the area of " foul ground " that occupies the north-east corner. On the northern shore of Putali and along the south side of the channel several palm-tree stumps are to be seen standing on the reef flat or at the margin of the channel, and the south side of the channel itself shows clear erosion in the presence of a steep bank down to the water, whereas on the northern side the bank shows a gently sloping beach of coral fragments (Pl. II, fig. 2).

Along the east side of Putali and the islands lying to the south of it the reef flat is comparatively narrow. As one traces it inwards from the nullipore zone one finds that the flat itself has a comparatively smooth surface, thickly dotted over with water-worn, usually flat, coral fragments, that are in the main aggregated into definite spits running out from the island (*vide* Pl. III, fig. 2). Agassiz (1903, p. 146) describes this area as follows : " The eastern edge of the reef flat is edged by a wide belt of masses of boulders reaching the very base of the shingle beaches on the outer face of the islands." On the inner side of the reef flat this boulder-layer slopes slightly upwards to join the island beaches, or else terminates in a slightly raised cliff of coral rock. Even at low tide this part of the reef flat is for the most part covered by about a foot of water, but along the outer edge of the reef flat a succession of coral masses are exposed above water. Opposite Mulikadu Island, which is the southernmost island on the eastern part of the reef, a small spit of piled-up coral fragments runs across the reef flat (*vide* Pl. VI, fig. 1), and in the shallow water to the south of this spit are a number of circular flat colonies of *Porites*, each being about 3 to 5 ft. in diameter, and showing live coral at the sides and a dead, eroded upper surface.

Along the whole length of the reef flat on this east side of the atoll I was unable to find a single "negro-head", and at low tide but little of the outer zone was exposed above sea-level.

On the south-west side of the atoll the outer reef differs in several points from that on the eastern side. The margin of the reef to seaward, *i. e.* the nullipore zone, is of the usual type and is similarly cut into buttresses and fissures, the whole being overgrown with nullipores. The fissure zone slopes slightly upwards to the level of the reef flat, which on this side is much wider in the greater part of its extent than on the east side. The outer part of the reef flat is here occupied by a broad boulder zone that is well exposed at low water, and consists of numbers of loose water-worn coral blocks and fragments that together form a slightly raised ridge, running along the outer part of the reef. Running inwards towards the islands with a north-easterly trend are numerous spits, composed of loose piled-up blocks of coral, and to the south, at the south-west point of the reef, this boulder zone merges in a series of eight small islets, composed entirely of piled-up coral boulders and coral rock (Pl. II, fig. 3).

Along the boulder zone on this aspect are scattered several large masses of coral, rounded and water-worn, which, though small in comparison with the blocks seen on islands in the Pacific Ocean, I have called "negro-heads". These have undoubtedly been torn off the outer face of the reef and have been hurled inwards and upwards on to the reef; the mass in the foreground in the photograph (Pl. II, fig. 3) shows clearly the broken base, facing the observer, and two rounded heads of the main coral growth; there can be no question that this fragment, now lying on its side, has been torn from its original site and flung on to the reef, and is not a dead mass of coral that originally grew in this position.

Inside the boulder zone the reef flat, even at low-water, is covered by about a foot of water, and along the south-west part of the atoll the flat presents several marked points of difference from the reef flat on the east. Extending in a line from just inside the series of small islands, that I have mentioned above, at the south-west point of the reef towards the north as far as the channel between Maradu and Hankadu Islands, is a series of "coral horses", from $2\frac{1}{2}$ to 3 ft. in height and composed of a hard, compact coral rock. Outside this line the reef flat is composed of a smooth, hard stone that appears to consist of coral masses cemented together. Inside the line of coral horses the character of the flat is different, and it consists for the most part of sand and beach sandstone, with scattered lumps of dead coral and occasional small colonies of *Heliopora* and madrepore, while large areas are covered with a considerable growth of a grass-like, red-brown alga, having blades from 2 to $2\frac{1}{2}$ in. in length (*Cymodocea* ?). On the shore side of the coral horses banks and spits of coral shingle have been piled up and run inwards towards the islands (Pl. III, fig. 1).

Further to the north the islands of Abuhera and Hitadu lie further out on the reef, which in this part closely resembles the reef flat on the east side of the atoll, and an outer rampart of water-worn coral blocks has been piled up along the island margin, very similar to that seen on the east side of Putali.

There can be little doubt that the differences in the reef flat on the east and west sides of the atoll are due to the different effect of the two monsoons. In spite of the atoll lying to the south of the equator and, therefore, more or less out of the main area affected by the south-west monsoon, the effects of the south-west winds are obviously considerably

greater than those of the north-east winds. On the south-west side of the atoll the waves have piled up coral blocks on the reef to a much greater extent, and have even at times torn off and thrown up large masses of " negro-heads ", which are never seen on the east side.

At the extreme south-west corner and along this face of the atoll the winds and waves, by erosion of the outer face and the deposition of sand on the inner, have driven the islands inwards across the reef flat for a very considerable distance, thus increasing the width of the outer reef flat (boat channel), and leaving behind as an interrupted ridge a line of coral rock that originally formed part of the base of the islands. The condition here exactly agrees with the account given by the Coral Reef Committee of the Royal Society (1904, p. 71), which points out that in the atoll of Funafuti " in some cases there is an outer line of extremely dense breccia, marking the most advanced position oceanwards occupied by that material at a time when it formed the foundation for islets which have since been driven inwards over the reef platform towards the shore of the lagoon ".

The northern reef, which is interrupted somewhat to the west of the middle of its length by the two entrance channels, differs from the rest of the reef by being almost entirely devoid of islands along its whole length. A few small islands stretch westwards for a short distance from the north-east point of the atoll, and the isolated portion of the reef, between the entrance channels, bears one small island, " Bushy Island ", and several small sand-cays. These sand-cays all possess the same shape and are crescentic, with the horns of the crescent pointing towards the west; it appears probable that they have been built up of drift sand during the north-east monsoon. The character of the northern reef differs markedly on the two sides of the entrance channels. On the east side the edge of the reef is everywhere composed of growing coral, whereas on the west side there is a well-marked, raised boulder zone, composed of piled-up masses of coral boulders. This difference I attribute to the general trend of the reef; on the west side of the opening the reef is exposed to the full force of the north-east monsoon, whereas on the east of the opening it is more or less sheltered from it by the projection of the north-east horn of the atoll, or at the worst is only raked by it.

THE ISLANDS OF THE REEF PLATFORM.

In most of the smaller atolls of the Maldive and Laccadive Archipelagos the main islands lie on the eastern side; at the southern end of the Maldives in both Addu and Haddumati atolls the north-east corner is occupied by a large island; further north, in Horsburgh atoll, the chief island, Goidu, lies on the north-east side; while further still to the north, in Minikoi and the Laccadive group, the main islands are situated on the east or south-east rim of the atoll; and in a previous paper* I have attributed this to the effect of the south-west monsoon wind and sea.

Commencing at the north-east corner of Addu atoll we have the island of Midu-Huludu. There appears to be no special name for the island itself; the names Midu and Huludu refer to the two villages that lie respectively at the north and south end of the island, but the former, Midu, has been applied by previous writers to the whole island. The island itself is roughly triangular in shape, its apex, with the surrounding reef, forming

* 'Mem. Asiatic Soc. Bengal,' vol. ix, pt. 8 (1935).

a well-marked projection towards the north-east. Stanley Gardiner (1903, p. 151), from his survey of the island, concluded that since the original survey by Moresby the north-east corner of the atoll and presumably therefore the north-east corner of Midu Island was growing outwards. A comparison of Moresby's and Gardiner's charts and the present state of affairs certainly appears to warrant this conclusion, and the structure of the island indicates that the extension, if it be real, has been brought about by the deposition of sand derived from the reef flat. Stanley Gardiner (1903, p. 417) describes the general structure of this island, as it existed in 1900, as follows : " Round the seaward side of the whole island, except at the extreme south end, the rock forms a narrow line, its greatest height about 5 ft. above the high-water mark." At the time of my visit the whole of the beach at the north-east corner and along the east side was composed entirely of sand and fine coral debris, mixed with shells and fragments of dried sponge, and a rock wall only appears at the southern end of the island (Pl. I, fig. 2). Along the east side of the island there is a belt, about 7 to 8 yards wide, between the thick jungle and the beach, and this is covered with weeds and a bush " scrub ", so that it seems probable that this strip of land is a recent formation ; this belt disappears at the southern end of the east side, where evidence of erosion can be seen. It would thus seem probable that Midu has to some extent grown outwards, and that this is due to the deposition of sand on its leeward shore during the south-west monsoon seasons.

The central portion of the island, which is thickly wooded, is depressed and is occupied by a large swampy area, in the centre of which is a stretch of open water about 200 yards long.

The inner or western shore of the island runs nearly straight in a north-south direction, except at the south-western point, where there is a small projecting area from which a small sand spit runs northwards, parallel to the shore, across the reef flat, and there is no raised inner rim or " lagoon-mound ". Stanley Gardiner has called attention to the formation of this spit, and he remarks (1903, p. 417), " it is evidently growing northwards and appears likely in course of time to cut off another " kuli " (water pool) from the sand flat ". The spit certainly appears to be growing, and is now Y-shaped, one arm running northward, parallel to the shore of Midu, while the other bends to the west, and the native inhabitants have built up a causeway across the mouth of the little bay thus formed, so as to complete the enclosed basin, the water of which is brackish. This spit is evidently caused by the current of water that flows from the outer reef flat between Midu and Putali islands ; the channel, which at first runs westward between the islands, turns to the north and is continued between the projecting south-west part of Midu and the narrow northward prolongation of Heratera, and then again swings westward to enter the atoll.

From the north-west corner of Midu a string of small linear islands runs westward along the reef flat ; this chain shows very interesting changes since its original survey in 1836. Originally six in number, in 1900 Stanley Gardiner found two small islets near the north-west corner of Midu, followed, after a small interval, by a chain of five more, that gradually decreased in size towards the west. In 1934 there are three islets near the north-west corner of Midu, and then, further to the west, come two more, of which the easternmost is narrowly linear and seems to have been formed by the fusion of other smaller islets. The last small islet in the series lies to the west of a linear strip of coral rock. A comparison of Stanley Gardiner's chart (1903, p. 415) and the condition of the

present day seems to indicate that the easternmost island, Balihura, has been broken up, and is now represented by the two small islands lying nearest to the north-west corner of Midu. Hika, the second of the series, appears to have remained more or less unaffected. After an interval we get at the present time the linear island that seems to correspond to the island Hera in Stanley Gardiner's chart, or possibly to that and the next following island ; but between this and the small island on the extreme west, which still survives, at least two islands have disappeared, and are now only represented by the line of coral rock to which I have already referred. It would appear probable, therefore, that these islands are also undergoing erosion.

The next island, to the south of Midu, is Putali (or Heratera), and both it and two other small islands still further to the south appear to have been derived from the breaking up of an originally single island, called Putali on Stanley Gardiner's chart (1903, p. 318). At the present day the island of Putali is long and narrow, and there were certain indications on both sides at the time of my visit that it was slowly being washed away. One would, however, have to visit these islands at different times of the year before one could decide with absolute certainty how far such an appearance of erosion is permanent or only temporary, as the local conditions differ markedly from season to season, owing to the alternating action of the two monsoons. In this connection I may note here that, as regards the islands on the western side of the atoll, the Head-man informed me that the area of land is continually altering with the season ; during the north-east monsoon the inner perimeter of these western islands, *i. e.* the lagoon side, is washed away, the degree of such erosion depending apparently on the strength of the monsoon, and on one island a strip of land bearing twelve palm-trees was thus eroded away in a single season ; at the same time the western or leeward side of the island tends to become increased in area. The opposite change takes place during the south-west monsoon ; the lee side, towards the lagoon, then enlarges, and the windward side tends to be washed away. The same process, must be going on in the islands on the east side of the atoll, though here the action of the south-west monsoon will not be so effective as that of the north-east monsoon since the height of the waves in the lagoon will be markedly less than that of waves in the open sea, though probably sufficient to cause a certain amount of erosion along the lagoon beaches, which will be to some extent, and possibly entirely, compensated by deposition of sand and a consequent extension eastward of the island, as seems to have been the case in the north-east part of Midu. During the north-east monsoon the reverse process will be set up, the island being washed away on its eastern side and a deposition of sand and a consequent extension taking place on the western or lagoon side.

A study of the two charts of this atoll, made respectively in 1836 and 1900, and a comparison with the condition present in 1934, reveals an interesting series of changes at the north end of this island, Putali. Originally, at the time of Moresby's survey, this island formed a long stretch of land along the eastern rim of the atoll, and to the south of it lay two smaller islands, followed, after an interval, by a third ; sixty-four years later, when Stanley Gardiner visited the atoll, it was found that a small island existed between Putali and Midu ; this, presumably, had been derived by the formation of a breach across the northern end of Putali, or possibly the southern end of Midu. Stanley Gardiner (1903, p. 47) remarks that " from the appearance of the channels through, to the N. and S. of Putali, it seems to me to be probable that the islands are coming together to form one continuous whole ". The conditions present in 1934 show, however, that the change

that has been going on to the north of Putali is not quite so simple as this. Putali and the small island to the north of it certainly may have joined but, as already shown, the bay between Huludu and Putali is slowly but steadily extending, and the northern part of the small crescentic island that in 1900 lay on the reef between the two islands has now, so far as I can judge, completely disappeared, though its former position may still be indicated by the interrupted line of coral rock that runs across the bay. In all probability the sand, that has been derived from the disintegration of the northern end of the island and from the erosion of the eastern shores that has formed the present bay, is being swept through the channel between the two islands, and is being deposited on the northern end of the spit that runs out from Putali on the lagoon side, since this appears to be extending northwards up the south-west side of Huludu, and its proximal part is gradually becoming covered with a low bush scrub, though the terminal part is still bare.

The structure of the three islands on the east side of the atoll, namely Putali and the two islands to the south of it, agrees closely with the description given by Stanley Gardiner of Minikoi (1903, p. 29). As already mentioned, in the northern part of Putali there is an exposure of old coral rock, which is now undergoing erosion (Pl. III, fig. 2). The seaward side of these islands consists of a raised rim of coral rock and boulders, while the western or inner side is composed of sand and shingle. As in other islands, the breadth of this seaward stony area varies in different regions of the same island, and in places it is a matter of some difficulty to draw a dividing line between it and the sandy inner part of the island, the coral boulders gradually getting fewer and fewer, so that the two areas grade imperceptibly into each other. The outer beach of Putali comprises several distinct zones. Along the outer margin (Pl. III, fig. 2), where the island abuts on the reef flat, there is a typical boulder zone, composed of numerous large lumps of water-worn coral, which at certain points are aggregated together to form spits that run out from the island towards the edge of the reef across the reef flat; it is impossible to say to what extent these coral boulders are derived from masses that have been torn off the reef edge, and have been flung inwards by the action of the waves, or from the gradual breaking down of the old reef rock by erosion and the consequent setting free of masses of coral that originally were embedded in it; probably both sources of origin are concerned, at any rate at the northern end, where the old rock is exposed and is undergoing erosion. Inside this boulder zone is a belt consisting of water-worn coral blocks mixed with sand, and, finally, the beach rises abruptly and is composed of water-worn slabs of coral; this rampart of coral blocks (Pl. IV, fig. 1) is several feet, usually three or four, in height above the general level of the island, and its inner landward side shows a gradual and typical "scree" slope. Many of these fragments are so water-worn that they now resemble fragments of flat paving-stone.

Towards the south end of Putali this rampart-like ridge of coral blocks gradually disappears and the beach becomes an ordinary shelving one, sloping gradually upwards from the sea-level; this part of the beach is composed of much smaller fragments of broken coral, with which a fair quantity of sand is intermingled. Between the two extremes of a high wall to the north and a shelving beach to the south is a region in which the beach consists of a double ridge, a high inner one composed of comparatively large boulders, which corresponds in position and general structure with the rampart-like ridge to the north and which falls away steeply on its seaward face, and a second lower ridge, composed of small coral fragments, forming a coarse shingle. Between these two ridges there is a trough-like depression. At the edge of the beach, near the water-level, is a belt of coral

rock consisting of fragments of coral much water-worn and cemented together by sand and debris. Stanley Gardiner (1903, p. 31), in his account of the atoll of Minikoi, has described a rampart-like ridge, very similar to that seen on Putali, but in consequence of a greater degree of erosion the face of the ridge is considerably steeper. In the case of the ridge on Putali the talus slope on the landward side shows clearly that the ridge has been thrown up, and I am inclined to regard it as the old boulder zone that was raised to its present height when the fall of sea-level brought the whole reef above the surface. Stanley Gardiner (1903, p. 417) has called attention to the fact that " Putali at its most southerly seaward point has also some fallen shrubs, but elsewhere none of the islands (of the eastern side of the atoll) showed any distinct change in progress ". At one point on the east side of Putali the sea has actually broken through the outer rampart, while at about the middle of the length of the island on the seaward side there is clear evidence of erosion going on. Here the shore curves inwards in a shallow small bay and the basal rock is well exposed, while the beach behind it also shows evidence of washing away in the shape of a steep fall from the top and the presence of bushes, that in other parts of the island rim are found growing just inside the top of the ridge of the outer beach, here standing on the seaward face of the rampart ; in addition fresh white masses of coral have been recently flung inwards over the top of the older black and water-worn boulders.

On the western side of the island, *i. e.* the lagoon side, the beach is composed almost entirely of fine sand, which gradually slopes upwards from the sea-level to the top of the ridge or " lagoon mound ", where this exists, for it is not present in the northern part of the island (Pl. IV, fig. 2). The contrast between the sand of the ridge and the inner reef flat, which consists of sand mixed with numerous small fragments of coral derived from the lagoon reef, is a marked one, and can clearly be detected all along the island when the tide is sufficiently low to expose the inner part of the reef flat.

At intervals along this beach there is also evidence of erosion ; at the extreme north end, where the island forms a well-marked promontory, the lagoon mound is absent, and several palm-tree stumps are standing on the lower slopes of the beach, and other palm trees have actually fallen owing to the sand surrounding their roots having been washed away. About half-way down the island the lagoon beach again shows clear signs of erosion, for at the top it terminates in a small cliff about 1 ft. high, and a number of bushes are actually standing in the water at high tide. Along this part of the beach there is a linear outcrop of sandstone that is horizontal, not sloping, like beach-sandstone, towards the lagoon ; it seems probable that this sandstone is part of the cay-sandstone that has formed beneath the sandy soil of the island and is now being exposed by erosion. The outcrop is situated almost exactly midway between the top of the beach and high-water level, and extends along the beach for some twenty yards or more (Pl. IV, fig. 3).

Towards the southern end of the island there is a slight indentation in the coast-line, and here the shrubs, which usually grow at the top of the beach, come right down to the high-water mark, and are in many cases being killed off by the salt water, and beyond this the stumps of others can be seen standing up out of the sand. All along this part of the beach there is an outcrop of beach-sandstone. At the extreme south end of Putali there is further evidence that the sea is encroaching on the land, for all along the beach are fallen trees, and in many places coco-nut palms, that are still standing, have their roots exposed owing to the sand having been washed away.

Every island along the eastern face of the atoll has at least one " kuli " or lake, and

in the case of Putali there has been a series of them extending along the whole length of the island. Stanley Gardiner stated that in 1900 there were about twelve, but owing to the continual deposition of sand on the southern part of the island many of these have now been filled up, and their original sites are only indicated by areas of dried mud, on the surface of which lie thousands of dead shells of *Pyrazus palustris* (Linn.). In this island the process of formation of these lakes appears to have been repeated, so that the lakes or pools form two series down the length of the northern part of the island. One series, representing the earlier formation, lies along the east side of the island close to the foot of the talus slope of the outer rampart; there are in all three pools in this situation, each of them containing brackish or salt water. The most northern (Pl. V, fig. 2) is the only one of the three that appears to have retained its original condition; in this the water has a salinity of 5·23 and a specific gravity of 4·15. The second of the series possesses a figure-of-eight shape and appears to have attained its present form by the union of two pools, one belonging to the earlier formation and the second to the later one; here again the water is brackish and has a salinity of 7·30. The last of the older series lies towards the south end of the island and also appears to have been formed by the union of two originally separate pools, both of which in this case, however, belonged to the early formation; at the northern end of this southermost lake the sea has within recent times broken its way through the coral rampart on the east side of the island, so that this now contains salt water; incidentally this provides further evidence that there is a process of erosion going on.

The second series of pools lies close to the western shore of the island in its northern half; they form a chain along a low-lying belt, that is bordered on its west side by the raised sandy lagoon-beach, while the eastern boundary is a steep sandy bank (Pl. V, fig. 1). These lakes would seem to be of comparatively recent formation. Running along the whole length of the northern part of the island, about 10 yards to the east of the steep bank that now forms the east bank of the lakes, there is a well-marked line of rounded, water-worn pieces of pumice. Stanley Gardiner (1906, p. 582) remarks, " One may point out that on the shores of many of the islands there are lines of pumice, which the natives state were washed up about 1885, and would hence have probably owed their origin to the eruption of Krakatoa in 1883. In addition, half-decomposed pumice is found, in places at some considerable distance inland, which evidently belonged to an earlier period ". The pumice that lies along this east bank of the lakes is little, if at all, decomposed, though it has become stained a brown colour, owing probably to contact with vegetable mould. Oldham (1895, p. 6) has recorded a similar deposit of pumice on Kardamat Island in the Laccadive Archipelago, and he remarks that " it is strewn all over the surface and varies in size from a marble to half a foot in diameter ". There can, I think, be little doubt that this deposit was derived from the explosion of Krakatoa, and that it was drifted up on the lagoon beach of the atoll at some subsequent period; if this be so, then since 1885 or thereabouts the inner beach of the island has advanced towards the lagoon by some 10 yards, and sand spits have been built out into the lagoon and have cut off the lake, forming a new lagoon beach on its western side, that in turn is also about 10 yards wide. All of these lakes of the second series, of which there are now three, the fourth having, as stated above, become fused with one of the lakes of the older and outer series, contain water that is only very slightly brackish or very nearly fresh; the specific gravity and salinity in these lakes, as we proceed from north to south, is as follows :

No.	Specific gravity.	Salinity.
1. Northernmost	0·89	1·21
2. Middle	2·13	2·74
3. Southern	2·25	2·88

All these pools possess one peculiarity in common, namely, that the water-level in them tends distinctly to rise and fall with the rise and fall of the tide, and this change is much greater at spring tides than at neaps. The regular ebb and flow of the water in wells on coral islands was noticed by Darwin in his account of the voyage of the "Beagle"; he remarks: "At first sight it appears not a little remarkable that the fresh water should regularly ebb and flow with the tides; and it has even been imagined that sand has the power of filtering the salt from the sea water. These ebbing wells are common on some of the low islands in the West Indies."

The fauna of these lakes presents several features of interest; since the lakes were originally part of the lagoon, one would naturally expect to find that the fauna was of an essentially marine type, and for the most part this is the case. Most, if not all, of the lakes, even the northern one that contained nearly fresh water, were inhabited by numbers of the Silver Mullet (*Chanos salmoneus* (Forsk.)), and contained large numbers of a species of *Leander* and numerous Amphipods, while the lake margin was frequented by enormous numbers of the mollusc *Pyrazus palustris* (Linn.). In one of the more recently formed pools on the west side of the island, however, were numbers of a species of *Melania*, a fresh-water species that must by some means have been imported. All around the margins of the lakes are numerous burrows of the large land crab, *Cardiosoma carnifex* (Hbst.), and as one walks through the scrub-jungle covering the middle and southern parts of the island one of these crabs or its hole is seen every few yards.

Continuing southward along the eastern rim of the atoll from Putali, we come to two small islands, Firai-du-hera and Kalu-hera, both of which, as their names would seem to imply, appear to have originally formed part of the island of Putali (or Heratera), but have since become separated from it. Moresby, in his original chart, made in 1836, shows two islands in this situation, the southern one being by far the larger of the two; Stanley Gardiner, on the other hand, only shows one. It is therefore a matter of very considerable difficulty to determine what changes have taken place in this part of the atoll but, so far as one can judge, the three islands, Putali and the two to the south of it, as shown by Moresby, became fused into one; at the north end a small island became separated off, as shown by Stanley Gardiner in his chart; and since 1900 there has been still further attrition, resulting in the disappearance of this separate island, partly by erosion and partly by fusion with the north end of Putali (now called Heratera), and the extension northwards of the main island on the inner and west side of Midu, while at the extreme south of Putali (or Heratera) two small islands have become separated off to form Firai-du-Hera and Kalu-hera. Both Moresby and Stanley Gardiner show only a single island in this position.

At low tide a ridge of solid coral rock, with a few slabs of water-worn coral scattered over it, connects all three islands, and the outer margin of each island between tide-marks consists of the same material and presents the same character. On the lagoon side of this connecting ridge between Putali and Firai-du-Hera the sand has been washed away by the inrush of water over the ridge at high tide, and, in consequence, there has been

formed a small but comparatively deep bay in which a few scattered colonies of a species of *Euphyllia* (?) are maintaining a precarious hold. At the north end of Kalu-hera is a small pool of salt-water that on its outer or seaward side is separated from the sea by a raised ridge of water-worn coral fragments, that drops steeply into the pool; judging from appearances the sea has comparatively recently broken through into the pool; the west and south sides of the pool are formed of gently-sloping mud and sand, in which a clump of mangrove trees are growing; these trees, though small and attaining a height of only 6 to 8 ft., are perfectly typical in character; the type of the fauna in the pool is essentially marine.

The last island on the eastern portion of the rim of the atoll, Mulikadu, is situated at a considerable distance from Kalu-Hera, though connected to it by a raised ridge of coral boulders, against which sand and shingle have drifted on its lagoon face. The position of this island is much further from the south-east entrance channel than is shown on the charts by either Moresby or Stanley Gardiner. The structure of the island is peculiarly interesting, in that it differs in several particulars from the other islands of the eastern rim, and forms one end of a series of which the island Midu is the other. Whereas Midu consists almost entirely of sand, Mulikadu consists almost entirely of coral boulders and shingle, and both inner and outer beaches are steep. The outer seaward beach has a marginal zone of coral rock that is raised some 2 to 3 ft. above the level of the reef flat, and immediately above this is a zone of loose coral boulders. Then comes a dazzlingly white steep beach of coral shingle, on which, at the time of my visit, numerous Terns, *Sterna melanauchen*, were breeding, their eggs being deposited on the shingle in ones and twos all along the beach (Pl. VI, fig. 1). The only other island on which these terns were breeding was a small sandy islet in the middle of the lagoon. At one point a narrow spit of coral boulders runs outwards from the island across the reef flat. The lagoon beach rises steeply from the water-line and, instead of being composed of sand, as in all the other islands on this side of the lagoon, consists of small water-worn coral boulders or fragments, so that it more closely resembles in its general appearance one of the seaward beaches. The surface of the island consists entirely of coral fragments or shingle, and looks as if it had been ploughed up by an enormous plough, ridge after ridge of coral and shingle having been thrown up, each one following the line of the inner margin of the island, and thus showing where from time to time fresh additions to the island have been piled up on its lagoon aspect. I have already mentioned (*vide supra*, p. 65) that at certain times of the year the north-west wind blows strongly, and that the effect of cyclones in the Laccadive Sea will be to cause strong gales from this quarter; and it is just at this point on the rim of the lagoon that the effect of such storms will be most strongly felt. It would appear from the structure of the island that during such gales the waves in the lagoon have sufficient force to cause the piling up of comparatively large coral masses, instead of the usual sand; further evidence of the growth of the island inwards towards the lagoon is to be found in a well-marked line of deposit of water-worn fragments of pumice that was, as in the case of the similar deposit on Putali, almost certainly thrown up after the explosion of Krakatoa in 1883; this line of pumice is now at a distance of some 20 yards from the top of the lagoon beach, indicating that this amount has been added to the island since that date. At the south-west end the island tapers to a point, and the upper ridge of the outer beach cuts sharply across the ends of the ridges of the inner part of the island; continuing the line of the island and running out in a south-westerly

direction is a spit of broken, water-worn coral, and beyond this the line of the reef is continued to the south-east entrance channel. The surface of the island is covered with low bushes, and in the central part there is a sunken area containing a small pool of very nearly salt water. The floor of the pool consists of a soft flocculent mud, forming a layer a few inches thick, below which there is a level hard rocky floor, that is undoubtedly part of the old reef flat. Living in the pool were numerous molluscs, and scattered here and there were masses of sponge, black in colour and with long digitiform processes, as well as patches of weed, on the branches of which were large numbers of a sessile Tunicate and several small brown Actinians, while numerous polychæt worms and amphipods were crawling in and out of the tangled masses of the weed clumps.

On the isolated part of the reef that lies between the two southern channels is situated the island Wiringili. As Stanley Gardiner (1903, p. 419) has pointed out, this island has been formed by the fusion of the two islands that were present on this part of the reef when the original survey was made by Moresby in 1836. Like Midu, the island is covered with trees and jungle, and in the centre of the eastern part of the island there is a pool of absolutely fresh water. A small isolated rocky islet lies to the south-west near the channel between Wiringili and Gan Islands.

A glance at the chart shows that the majority of the islands on the western part of the rim of the atoll are larger than those on the eastern side, and are situated much nearer the inner margin of the reef platform ; they are all separated from one another by channels through which, even at low tide, the water on the outer reef flat has direct access to the lagoon ; these islands are also much more heavily wooded, except in one or two small areas, than the eastern islands, and instead of being covered by a low bush-scrub, they bear a number of large trees, conspicuous among which is the Jack-fruit Tree.

Commencing at the southern end, the first island is Gan, situated close to the inner reef and heavily wooded ; its northern shore lies close to the lagoon reef, but separated from it by a boat-channel. Both northern and southern shores are sandy and, judging from previous charts, the island appears to be gaining in size, on both faces.

The next island, Faidu, is also thickly wooded, and the beach at its north-western end consists entirely of sand, sloping gently upwards from the water level to the general level of the island. Stanley Gardiner (1903, p. 419) has called attention to the fact that on its seaward side this island is being washed away : " On the seaward side of the east end of Faidu there is a good deal of fallen timber, showing washing away, and between the island and the boulder zone are no less than 15 masses of rock on the reef." As I shall have occasion to point out later, this process, which is, I think, more of the nature of an " inward drift " across the reef flat than one of simple erosion, the area lost on one side being added to the island on the other, has affected all the islands on this part of the reef flat to a greater or less degree. Between Faidu and the next island, Maradu, is a deep channel, which, however, shoals considerably at its inner lagoon end, where a bar of sand and rock tends to connect the two islands ; even at low-water this channel does not dry completely ; patches of rock project above the surface, but do not prevent the free access of water from the outer to the inner reef flat. It is probable that this line of rock represents a former connection between the two islands.

On the west side of Faidu and opposite the channel between it and Maradu Island there is a series of six small islets, situated on the boulder zone close to the edge of the reef. Between these islets and the islands of Faidu and Maradu there is a wide shallow

channel, the floor of which consists of sand and coral fragments, with here and there small isolated colonies of *Porites* or Astræidæ and a small quantity of weed. On the east or shore side of this group of islets, but separated from them by a narrow channel, is an outcrop of coral rock, about $1\frac{1}{2}$ or 2 ft. in height. The islets themselves are situated on the edge of the boulder zone and, like the islands on the eastern part of the atoll, their seaward face in most cases consists entirely of a ridge of water-worn coral boulders, at the foot of which, on the sea side, is a belt of coral rock. The inner face of these islands consists of sand and shingle. The most northerly of the series differs somewhat from the others in that it consists of a mass of exposed coral rock on its seaward face, against which coral shingle and sand has been piled up, and now forms several spits running across the reef flat towards the inner islands; in this respect it more resembles the small isolated islet that is situated further to the north on this side of the atoll opposite the island of Hangadu. Some of these islets are entirely destitute of vegetation, but on the largest of them there is a low scrub jungle, composed of bushes similar to those found on the islands on the eastern part of the rim, and a few palm trees have maintained a hold on the sandy area to the east of the boulder ridge. Spits composed of coarse coral shingle and small boulders run inwards from several of these islets towards the island of Faidu, only a narrow strip of water, about 6 in. deep, separating them from each other at low tide.

Stanley Gardiner (1903, p. 419) called attention to the presence of these islets on the outer reef flat, which were unrecorded on Moresby's original chart; at the time of his visit in 1900 there were "seven small uncharted islands between Faidu and Gan and the seaward edge of the reef. The first of these is a small stony islet just inside the boulder zone opposite the centre of Gan". This is still present, but appears to be much reduced in size. "Then there is a sandbank in the corresponding position of the west end of Gan"; this has now disappeared. "Off the centre of Faidu, and opposite the passage between Faidu and Maradu, was a large coco-nut-covered island, with outside it three smaller islets covered with low bushes, an additional stone bank with a few shrubs lying to the north." If we number Stanley Gardiner's series from 1 opposite the middle of Gan to 8 at the extreme north of the series, and compare them individually with those now present, it seems, as mentioned above, that No. 1 is still present, though reduced in size; No. 2 opposite the western end of Gan has completely disappeared, and so probably has No. 3 opposite the channel between Gan and Faidu. No. 4 is present, though to all appearances somewhat reduced in size. Nos. 5 and 6 appear to be unchanged. No. 7, the largest of the series at the time of Stanley Gardiner's visit, appears to have now been broken up, some of the coco-nut trees still managing to survive, but the washing away of the inner part of the island has laid bare the mass of coral rock mentioned above. No. 8, the stone bank that Stanley Gardiner mentions, is still persisting. On the whole the evidence would appear to be in favour of the view that these islets are undergoing slow erosion, rather than that they have been recently formed, and, therefore, that for some reason or other they were overlooked by Moresby when he made his original chart.

The next island of the series is Maradu; this is narrow and linear in shape and presents differing characters in its northern and southern parts. The northern part comprises about one-third of the whole island, and the formation of a bay on each side gives rise to an appearance as if the southern part had been displaced eastward or toward the lagoon. At the southern end of the island, where it faces Faidu Island, there is practically no beach at all; the island terminates in a small cliff about 2 ft. in height, which is thickly overhung

by bushes, so that anyone attempting to walk round this end of the island has to wade through water about a foot deep even at low tide. About 6 ft. from the end of the island the floor of the channel between it and Faidu drops steeply into deep water. The south-west corner of Maradu is composed of coral shingle, and here there is a small cliff about $2\frac{1}{2}$ ft. in height at the top of the shingle beach, along which the roots of overhanging bushes are exposed. It seems evident that at this point the island is being washed away. All along the west side of the southern portion of the island the beach at the time of my visit consisted of almost pure sand with a slight admixture of coral shingle, etc. On the northern side of the bay that forms the line of demarcation between the two parts of the island on its western side there is a wide expanse of coral conglomerate that runs out from the island towards the outer reef. This conglomerate is horizontally bedded, and is composed of masses of water-worn coral fragments that have become consolidated, and from its general character it seems that this formation is a part of the old reef flat that was originally laid down at some distance from the reef edge, as, for instance, in the shingle or boulder spits that run in from the boulder zone or reef crest, and subsequently became consolidated into a conglomerate rock ; at the present day this rock is being steadily eroded away, and in places there are isolated blocks that are now completely surrounded by water and are much under-cut (Pl. VI, fig. 2). At the foot of this outcrop there are in sheltered places small collections of coral fragments that have been eroded out of the conglomerate. To the north of this point the beach slopes steeply upwards to the level of the island, and consists of sand and shingle with numerous outcrops of a fine coral conglomerate, gradually changing in character, as one proceeds northward, to a beach-sandstone ; in one place near the north end there is a smooth expanse of what looked like beach-sandstone, but which on examination proved, instead of being hard, to be soft, like a thick clay. The north-west corner of the island is being gradually washed away ; at this point there is a small cliff, about 2 ft. in height, along which the roots of trees, blocks of coral and coral shingle are exposed, and at one point, where originally an old lime-kiln for burning coral formerly stood, the cliff has fallen away, leaving only half the kiln still standing. On the lagoon side of the north end of the island a series of three sandspits run inwards towards the lagoon reef, and these are connected at their ends by a sandbank, which at low-water spring tides is only covered by about a foot of water, and which is continued to the north to connect with a similar sandbank running out from the south end of the island of Hankadu, the next island to the north. The lagoon beach of the northern end of the island consists entirely of sand, and slopes gradually up from the water-line. In this part of the island a well-marked line of pumice can be seen, running parallel to the foreshore, but about 10 to 15 ft. inside it. This line probably indicates that this amount has been added to this side of the island since the explosion of Krakatoa in 1883. It is interesting to note that this is almost the only part of the north end of the island that bears coco-nut palms, the western part being covered with a low scrub jungle, that closely resembles the vegetation on the islands of the eastern part of the atoll, especially Putali and the islands to the south of it. As one proceeds further to the south along the lagoon beach one finds outcrops of beach-sandstone, and this is especially the case where the land juts out towards the lagoon reef to form the south shore of the small bay, where the northern and southern parts of the island meet. Close to this bay a pit was dug in an attempt to find fresh water ; in the topmost 4 ft. we encountered at first a layer of earth, mixed with roots of trees ; then came a layer of white sand, below which

was a stratum in which the sand had become consolidated into a sandstone. Under the sandstone was a second layer of sand, and then came a mass of coral boulders, the old reef platform. It seems clear that this island is steadily being driven inwards across the reef platform and, moreover, that this process has been going on for some considerable time. The western side of the island is undoubtedly undergoing erosion, while the eastern side is to some extent eroded during the north-east monsoon, but during the south-west monsoon sand is piled up on the lagoon or leeside of the island, and this more than counterbalances the process of erosion.

The line of coral horses on the outer reef flat, to which I have referred above (*vide supra*, p. 71, and Pl. III, fig. 1), indicates, I think, the original line of the outer or seaward face of the island, and the small islands on the reef flat that lie in the same line as the "coral horses" may possibly also be parts of the original island, in which case the inward drift of the island would appear to have been greater in the southern than in the northern part of the island.

The next island, Hankadu, is separated from Maradu by a channel that contains deep water in the central part between the islands, but which shoals considerably both at its inner and outer ends. Towards the west it shoals to join the reef flat, while at its lagoon end there is, as I have already mentioned, a sandbar on the lagoon reef flat connecting the sand spits from the two islands. The floor of the deep part of the channel is plentifully overgrown with scattered colonies of stag's horn coral (*Acropora*), and in the shallower water on the west side were several small colonies of *Heliopora cœrulea*. According to Stanley Gardiner (1903, p. 418), at this point "there are traces of a former passage into the atoll lagoon in a less consolidation of both the seaward and lagoon edges of the reef, the latter being still very imperfect and the former having practically no boulder zone". I cannot agree with this. I could detect no trace of any less consolidation in the outer reef, and the defect in the lagoon reef, which is certainly present at this point, I attribute to the detrimental effect on coral growth of the sand and silt that is at every rise of the tide swept off the outer reef flat, through the channel, on to and across the lagoon reef at this point.

The island of Hankadu is small and comma-shaped, its southern end running out in a curved, narrow spit. Lying to the west of this southern area in the concavity of the curve, but separated from it by a fairly deep channel, is a small unnamed islet that is completely destitute of vegetation, and consists merely of a line of coral-rock on its seaward face and a raised bank of coral shingle on its lagoon side. It is interesting to try and trace the history of this small island Hankadu and its associated islet. In Moresby's original chart there is no trace of any island in this situation, but at the time of Stanley Gardiner's visit in 1900 an island was present and is shown on the chart that he gives (1903, p. 415), while he remarks (*loc. cit.*, p. 418) that it "has a narrow rocky line". The shape of the island, however, as given by him is very different from that of the present day, and there was apparently no trace of the accompanying islet. It seems probable that both Hankadu and the islets were originally part of the island to the north, now known as Abuhera, but shown in Moresby's and Stanley Gardiner's charts as Ru-jehey Hera or Ruehi-Hera, and that it first became separated off as a small island, as shown by Stanley Gardiner, and then since his visit has been still further eroded and split up into the small island and its attached islet that I found, while there has at the same time been an inward or lagoon-ward drift of the sand-spit at the south end of Hankadu. This island, or rather the mass

of coral rock that forms its west side, represents the northernmost extension of the line of coral horses and the small rocky islets that runs down the outer reef flat on the west side as far as Faidu and Gan Islands.

The next island, Abuhera or Ruehi-hera, appears to have originally been continuous with the island Hitadu to the north, and in Moresby's chart they are shown as parts of one island, the northern portion being called Hitadu and the southern Ru-jehey Hera. At the present day this island is completely separated from the islands to the north and south of it by channels, though from its southern end a sand-spit runs out into the channel towards Hankadu. Both in its structure and general appearance this island differs from the other islands of the western rim and much more closely resembles those of the eastern side. The island lies much nearer to the reef margin than the islands further south, so that the outer reef flat is in this part comparatively narrow and the island comes close to the boulder zone. At the southern end of its western side the island is built up of rounded and water-worn coral boulders, that form a raised ridge along the sea face, similar to the condition found in Putali on the east side of the atoll (Pl. IV, fig. 1), but conspicuously absent from the other islands on the west side to the south of this, though closely resembling the character of the small islets of the reef flat on the west of Faidu and Gan. The outer face of this boulder beach slopes steeply down to sea level. Inside this beach the rampart slopes down in a talus slope to the general level of the island, that is here covered with a dense scrub. Further north the boulder beach becomes replaced by a coarse shingle in the upper part of the beach, and shingle mixed with sand in the lower slopes, while outcrops of coral rock are met with. At the north end of the island two spits of coral boulders run outwards across the reef flat, exactly as they do on the east side of the atoll. The inner or lagoon side of the island is bordered by a beach composed entirely of sand, which has a steep slope that at the extreme south end of the island becomes almost vertical. Along the lower slopes of the beach at many points there is an outcrop of beach sandstone, showing the typical laminated structure, and beyond this there is a sharp drop of about 2 ft. The central portion of the island is depressed, though there is no " kuli " or central pool of water, such as one finds on the islands of the east side. The vegetation of the island consists almost entirely of a bush-scrub, with scattered coco-nut palms and Pandanus trees. The structure of the island clearly indicates that it has been built up on or just internal to the boulder zone, and that sand has drifted against the leeside of the raised beach ; the inward drift of the island has been comparatively slight in comparison with the amount of drift that has taken place in the islands of Hankadu, Maradu and Faidu to the south. The separation of this area of land from Hitadu appears to have been of recent occurrence ; even in 1900 no such separate island seems to have existed. Stanley Gardiner in his chart (1903, p. 415) gives no indication of any separation, though he remarks (*loc. cit.*, p. 418), " by Ruehi-Hera (the name given to the southern extremity of Hitadu Island) there were signs of an irruption of the sea across the land, but no definite gap was created ". Since 1900 this gap has become definitely established, and the detached area of land now forms the island Abuhera.

The last island to be considered on the west side is Hitadu. This is a long island, occupying the north-western horn of the crescent. I was only able to pay a single visit to this island and am, therefore, unable to give any very detailed account of it. The lagoon beach in the part that I saw consisted of sand and shells, but at the northern end this is replaced by coral boulders, and a narrow spit of the same material runs towards the south,

enclosing a large shallow area with a sandy bottom much overgrown with weed. Continuing the line of the spit are two small islands, both of which are built up of coarse coral shingle, with a certain amount of sand. The western side of the island consists in the main of a beach of coral boulders, with exposures of coral rock along its margin ; and for some distance in from the beach the island appears to be composed of weather-worn fragments of coral, on which a number of scattered bushes have obtained a foothold. Towards the northern end the coral-boulder beach is replaced for some distance by a sandy one, and then the boulders begin again, and the whole of the extreme northern end of the island is built up of these coral masses. Somewhere on the island there is a pool of fresh or nearly fresh water ; I did not see it myself, but the local inhabitants brought me a number of examples of a small fish of a species of *Barbus*, and several tadpoles, probably those of *Bufo melanostictus*, since this is also found to exist and breed in a small artificial pool that has been constructed on Maradu Island, and they informed me that they obtained them from a large pool on the island.

The northern part of the reef platform is almost destitute of islands. I have already mentioned the linear series of small islets that occur on the west side of Midu (*vide supra*, p. 73). The isolated part of the reef between the two northern entrances bears one small island, Bushy Island, and two sand-cays. The island is roughly shaped like a Greek ν, and enclosed between the diverging horns is a pool of salt water that has been converted into a fish-trap, a wall of stones having been built up across the gap, so that the sea flows in as the tide rises, while on the ebb this area becomes cut off and thus any fish that have made their way in are trapped. This island seems to have increased in size to some extent since Moresby made his original survey, for he shows it as a sandbank with a few bushes, whereas at the present time it is covered with trees and jungle. The main area of the northern reef is destitute of islands, and I believe that the reason for this is that they have all been washed away.

To sum up the results of my survey of the islands, one must conclude that with the exception of the north-east part of Midu Island in the north-east horn of the atoll, which seems to be growing out, though it is being eroded away on its lagoon aspect, and is thus drifting across the reef flat in the opposite direction to most of the other islands, and possibly also with the exception of Hitadu at the north-west angle and Mulikadu on the south-east side, which appear to be more or less stationary, all the other islands are undergoing erosion on their seaward faces. In every case the presence of coral rock along the beach indicates that the upper layers of the beach are being removed, and the rocky substratum, which was originally part of the old reef flat before the fall of sea level raised it to its present height and caused the formation of land, is thus laid bare and is in its turn undergoing erosion. Erosion is further indicated by the presence of fallen trees or dead and dying bushes along the sea face, together with cliffing of the beach. The amount of erosion that has been so far achieved differs on the two sides of the atoll, and is considerably less on the north-east and east sides than on the south-west and west ; this is only what one would expect from the different strengths of the two monsoons. On the east side the islands for the most part have not yet been driven in beyond the extent of the boulder zone, though one island has completely disappeared. On this face of the atoll, with the exception of Midu and the northern part of Putali, which have doubtless been modified by human agency, the general type of vegetation on these boulder-zone islands is a low bush-scrub, with occasional palm-trees. On the western part of the rim,

and especially in the islands of Maradu, Hankadu and Abuhera, a greater degree of erosion has taken place and now the islands lie well inside the boulder zone, often with a wide stretch of water between them. On the boulder-zone itself are a few small islets, as we have already seen (*vide supra*, p. 81). As regards these latter, Stanley Gardiner (1903, p. 419) has attempted to explain their presence as a new formation ; he remarks, " Considering the whole formation, I am driven to the perhaps rather lame conclusion that the physical conditions in the S.W. of the atoll differ from those in other parts sufficiently to have in the first place produced a broad reef flat, largely by the washing away of the land, which loss is now being repaired by the formation of a fresh series of islands along the boulder zone of the reef ". I think that Stanley Gardiner was inclined to lay too much stress on the absence of any indication on these small islets of the boulder zone in Moresby's chart. Throughout the whole of this south-west part of the atoll there is conclusive evidence that the islands are being steadily driven inwards across the reef flat, and traces of their original western boundary can still be seen in the shape of blocks of hard coral breccia, the so-called " coral-horses ", in a linear series just inside the present boulder zone, the last of the series to the north being at the present time gradually laid bare by the erosion of the small islet of the south-west side of Hankadu. It seems clear to me that the islets to the west of Faidu and Maradu are equally the last remaining traces of the original western extension of these islands that, as in other islands on the boulder zone, at one time possessed a sea beach composed of a base of coral rock, surmounted by a rampart of coral boulders ; parts of this original sea beach still remain, having been sufficiently firm and dense to resist erosion, though breaches occurred at intervals, and the softer and less resistant sand and sandstone of the island were washed away, leaving these traces still *in situ*, though gradually disappearing.

The vegetation of the islands on the western side of the atoll is in most of the islands much more dense than in the islands on the east, but here, too, in those islands that still maintain their original position in or near the boulder zone, we find that the greater part of the area, and especially the outer part of the island, is covered with a low bush-scrub, exactly comparable to that seen in the islands on the boulder zone of the east side.

One other point that seems worthy of consideration is the different character of the shingle and boulder spits that are found crossing the outer part of the reef between the islands and the boulder zone. In certain areas these run inwards from the boulder zone towards, but not reaching the island beaches, whereas in others the spits appear to run out from the islands towards, but not actually reaching the boulder zone. This difference I attribute to the degree to which erosion and the inward drift of the islands have taken place, and I regard the two conditions as successive phases in the process of erosion. At the commencement of erosion of an island, which typically consists of an outer rocky rampart and an inner sand flat, the sandy area is driven lagoon-wards and a line of separation between it and the rock rampart is established. In the next stage the island, now composed for the most part of sand, is still further driven lagoon-wards, and the rocky rampart becomes breached and eroded, coral boulders being set free from the rock, and these are driven inwards to form spits running islandwards from the line of coral horses on or near the original boulder zone. With further erosion the coral horses become gradually broken down and ultimately disappear, while the boulder spits are still further driven inwards and now reach as far as the island beach, against which they become piled, and eventually may form a new rocky rampart. If this be so then the island of Putali

on the eastern side and the northern end of the island of Abuhera on the western, though actually not so far removed from the present boulder zone as the islands Maradu and Faihu on the south-western side. represent a more advanced stage in erosion ; and this is further indicated by the complete absence of any coral horses on the reef between them and the reef crest. At first sight this may appear to be unlikely, since the distance between the reef crest and the islands Maradu and Faihu is far greater than between the reef crest and Putali or Abuhera ; but it must be borne in mind that the more rapid erosion may be due to a less consolidated condition in the original reef at the points where Putali and Abuhera now stand, and a greater consolidation opposite Maradu and Faidu ; and this is what one would expect, since at the south-west point of the atoll the waves of the south-west monsoon will be felt to a greater extent, and will therefore give rise to a condition that is more favourable to the growth of nullipores and the consequent hardness of the reef face.

THE LAGOON REEF.

Just as the islands on the reef platform exhibit considerable differences on the two sides of the atoll, east and west, so there is a marked difference between the lagoon reef of the two sides. Commencing at the north-east corner of the lagoon, the inner reef flat is here over a mile wide and a large portion of it dries completely at low-water spring tides. Along the inner side of the northern reef platform the edge of the reef is well defined, but at the north-east corner there is a break in its continuity, and a second line of dead coral reef that at low tide shows well above the water level, running in a north-south direction, lies across the mouth of the gap between Midu and Heratera Islands. To some extent obstructing this gap in the reef and extending further inshore are numerous isolated patches of coral, that rise almost vertically from the sandy floor of the lagoon to within a foot or two of the surface, leaving between them a network of small channels that have a depth of 3 to 5 fathoms of water. The whole of this north-east corner of the lagoon thus forms an area of what is technically termed "foul ground". Stanley Gardiner (1903, p. 318), in his account of the lagoon of this atoll, describes at this point of the lagoon a continuous inner or lagoon reef, and between it and a second inshore reef an elongate area of deep water or "velu", with a depth of 5 fathoms. A comparison of this account and the condition as I found it in 1934 seems to show that the inner lagoon reef at this point has been broken down, and all that remains of it is a scattered "jungle" of coral heads that rise from 3 to 5 fathoms with passages between the pinnacles. I have already pointed out that erosion is going on in the bay on the outer reef between Midu and Putali, and that with the rise of the tide quantities of sand and mud are swept through the channel between the two islands and over the reef flat on the west side ; and it seems to me that at the present time the destructive effect of the mud and sand, combined in all probability with the ravages of boring organisms, has caused a breaking up of the lagoon reef at this point. Further to the south, where the lagoon reef becomes continuous, the bulk of the reef is composed of masses of dead coral, which have become more or less cemented together by smaller fragments and by an admixture of sand and of the remains of other calcareous organisms. For the greater part of its length the upper surface is covered by several inches to a foot of water even at low-water spring tides, but in places occasional colonies of living coral growing on the surface of the reef are (Pl. VII, fig. 1) exposed for a short period, and large masses of dead coral project for a foot or two above the surface. These

large masses of dead coral are eroded and water-worn, but they appear to be still standing *in situ*, and in many cases are far too large to have been thrown up on the reef by such waves as even a gale from the south-west could raise inside the lagoon. The only conclusion to which one can come is that we have here evidence of a relative alteration in the sea- and land-level, and that they are the remains of the old lagoon reef that has not yet been completely destroyed. If this be so, then it is clear that the lagoon reef in this part of the atoll has been stationary for a very long period of time. In places the surface of the reef is composed of round or oval masses of Astræaceæ, the upper surface of many of which has been killed off and is now composed of dead coral, often hollowed out in " pot-holes " ; scattered over the surface of the reef, either in these pot-holes or on the dead coral, are a number of colonies of live coral, conspicuous among which are oval or rounded colonies of the " corymbose " type of madrepore (*Acropora*) (Pl. VII, fig. 2), together with small colonies of *Pocillopora*, *Coeloria*, *Seriatopora* and various species of Astræaceæ, while examples of *Fungia*, in both the free and sessile stages, are not uncommon ; among the coral small patches of a yellow Alcyonarian are not uncommon. Taken as a whole, however, the coral growth on the reef is not luxuriant. The inner margin of the reef slopes downwards towards the lagoon for a few feet, and then drops steeply down to a depth of 8 to 10 fathoms. This inner wall of the reef can be seen on a calm day to be built up of large masses of solid coral, and the surface is thickly studded with growing colonies of madrepore, while in places, commencing about 3 ft. below the surface, are large colonies of a fan-shaped madrepore coral of a pale yellow colour ; when viewed from the surface this latter growth closely resembles that of a gigantic cup-coral, but actually it is composed of very stout broad plates, expanded more or less horizontally, with a few short branches growing out from the edges. At a still greater depth, and commencing usually at about 1 fathom, and so sufficiently deep to be unaffected by the damaging force of the lagoon waves, are large colonies of a dark brown, slender stag's-horn madrepore. These branching corals are usually inhabited by crabs and brightly-coloured fish, while the masses of Astræaceæ are studded with numerous Serpulid worms of all hues, red, orange and blue being the prevailing colours. A few Crinoids of a brown colour and an occasional large brown Holothurian can be seen attached to the surface, while in the grooves between the rounded masses of solid coral are examples of *Tridacna*, whose mantle, when the valves are open, is easily recognizable as a vivid patch of colour, usually blue or purple.

The reef flat at the north-east corner is over a mile wide and for the most part the water covering it is shallow ; the level slopes downwards gradually as one proceeds out from the beach, until near the reef there is a depth of 3 to 5 fathoms, but inshore at low-water spring tides extensive areas are laid bare. This flat is composed of a mixture of sand and lamellibranch shells, and large areas are covered with a grass-like plant (*Cymodocea* ?), but the greater part is bare of weed, and the sand is thrown up into numerous mounds by burrowing organisms. In one or two places towards the lagoon edge of the flat masses of dead coral still stand, showing where coral-heads originally flourished. On this part of the flat I only succeeded in obtaining one Sipunculid and a few Polychæt worms, together with a few specimens of a species of burrowing crab of the genus *Macrophthalmus*. In the channel connecting the inner and outer reef flats between Midu and Heratera examples of a black Holothurian, *Holothuria atra* (?), and a species of *Synapta* are common, while the sand and shingle is thrown up into mounds by burrowing Holothurians, white in colour with pale brown mottlings, that usually lay at a depth of about

6 in. below the surface. Further south on the west side of Putali the inner reef flat is considerably narrower and is only some 600–700 yards across ; considerable stretches dry at low water, but as one proceeds southwards the amount laid bare by the tide diminishes. Along this part of the reef flat the floor consists of sand mixed with small fragments of coral ; in the shallow water towards the island beach there are occasional small masses and boulders of dead coral, with patches of *Halimeda*, but towards the lagoon reef patches of coral become of more frequent occurrence and are of larger size, and, instead of being completely dead, living coral is in places maintaining a somewhat precarious existence. Near the reef itself the water has a depth of about 3 fathoms, and there is a well-defined boat channel, that is, however, considerably obstructed by large masses of growing coral.

Stanley Gardiner (1903, p. 321) states that Holothurians and Sipunculids, two of the most important sand-triturating organisms, were singularly scarce in Addu atoll, both on the reef and in the lagoon. This, however, was not my experience. I have already mentioned that in the channel between Midu and Putali both *Holothuria* and *Synapta* are common, and the same is true of the adjoining part of the outer reef flat. On the inner reef flat to the west of Putali at least three species of Holothurians are common ; just on the shore side of the lagoon reef they are particularly common, especially a species that either is, or closely resembles *Holothuria atra* ; a fairly conservative estimate of the frequency of occurrence would be one in every square yard of reef surface. Further inshore in the shallower water opposite Putali there was one in about every two square yards, and these examples were for the most part small, measuring only 6 to 8 in. in length, and though black in colour, were rendered much less conspicuous by a thick dusting of sand over them.

In the south-east corner of the lagoon the line of the lagoon reef becomes irregular and is broken in one or two places, while inshore, between it and the islands, we again find an area of " foul ground ", the surface of the reef flat being covered with a maze of growing coral. Opposite Mulikadu and the boulder ridge connecting it with Kaluhera the water on the reef-flat shoals gradually, and the floor consists almost entirely of a coarse sand and shingle, while thickets of stag's horn madrepore grow up from its surface. It would seem that at this point the inner lagoon reef is being destroyed, and fragments of coral and sand derived from the lagoon reef are being swept across the reef flat and, as we have seen (*vide supra*, p. 79), during storms from the north-west are flung up on the island. It is of some interest to note that in such situations, where there is reason to suspect considerable movement of sand along the bottom, stag's horn madrepore appears to be the only type of coral that can maintain its existence ; as I shall mention later (*vide infra*, p. 91), on the west side of the atoll in the channels between the islands and on the margins of the sand bars that nearly completely obstruct their lagoon ends we get similar thickets of stag's horn coral ; presumably the explanation of this is to be found in the liability of other species of coral, that have a less elevated type of growth, to be sooner or later smothered by the sand, and so killed off. Even in these thickets of stag's horn coral the supporting trunks are dead and overgrown by a filamentous alga, and only the terminal branches and twigs are still living and healthy.

On the south-west and west side of the lagoon the reef shows several points of difference from the reef on the east. In the first place, the reef itself lies much nearer to the island beaches than on the east, this, of course, being due to the degree to which these islands of the western side have been driven across the reef flat and have, in

consequence, approached the inner or lagoon reef. In this segment of the atoll the inner reef flat is only some 200 yards wide and the water over it is shallow; opposite Gan Island there is a small boat channel between the reef and the island that communicates with the lagoon by one or two narrow openings through the reef, but further to the west, off Maradu Island, there is no definite boat channel, and the depth of water between the reef and the island is only a few feet. On this western side, and especially on the inner or lagoon part of the reef flat, the growth of coral is much more prolific than on the east. Stanley Gardiner (1903, p. 319) remarks that the coral growth in Addu atoll was more luxuriant than anything that he had seen elsewhere, and certainly this portion of the reef would seem fully to justify his description. The reef flat opposite Maradu Island is wide, and its upper surface, which is well exposed at low-water spring tides, appears to consist of four zones. The inner zone nearest the lagoon slopes slightly downwards to the edge of the reef; it consists of a foundation of dead coral rock upon which are growing numerous, closely-set, rounded or oval colonies of madrepore (*Acropora*), each colony measuring about 1 ft. in diameter. These colonies are very similar to the colonies that I have already mentioned as growing on the upper aspect of the lagoon reef on the east side, but here they are vastly more numerous. The actual inner margin of this zone is cut up by numerous small gullies and fissures, that run somewhat irregularly over the surface and remind one of the fissure zone of the outer reef (Pl. VIII, fig. 1). Immediately outside this zone is a second one, about 5 yards wide, in which the surface of the reef flat is almost level and resembles a road that has been made of very coarse cobble-stones; the whole of the surface of this part of the reef consists of closely-set, small colonies of Astræids, and in every case the central part of the colony, which usually measures some 9 in. across, is dead and eroded, only the perimeter of the colony consisting of living coral. Scattered over this zone are small water-worn masses of dead coral, and the number of these increases as one proceeds northwards toward the part of the reef that lies opposite the extreme north point of Maradu Island, where they constitute a third zone along the shore side of the reef. The fissured character of the reef margin and the increasing prevalence of these dead coral boulders, that suggest a boulder zone in miniature, as one proceeds northwards along the reef, is probably correlated with the increased effect of the swell that during the south-west monsoon sets in to the lagoon through the southern openings and then sweeps in a north-westerly direction across the lagoon, the force and height of the breakers increasing from south to north along the reef. Proceeding still further outwards towards the islands the next zone slopes downwards away from the lagoon and is covered at low-water spring tides by 6 in. to a foot of water; here the floor of the flat is composed of coral rock with a small admixture of sand; the coral growth is particularly luxuriant, and forms a wide belt that spreads inwards towards the islands. So profuse is the growth of coral that it is quite impossible to describe it in detail, but the photograph of it (Pl. VIII, fig. 2) shows this clearly. Patches of stag's horn coral, for the most part brown in colour with white tips to the branches, abound, and here, too, the lower parts of the main stems are usually dead and overgrown with a filamentous alga. Numerous colonies of Astræaceæ, as well as *Pocillopora*, *Seriatopora* and patches of leathery Alcyonarians, are scattered over the reef flat, while giant Actinians of the genus *Discosoma* and numerous Holothurians, of several species, are to be seen. Further inshore in the last zone this coral growth becomes patchy in character, and simultaneously the floor of the reef flat changes to sand, and finally the coral growth ceases entirely.

Opposite Maradu and in one or two other places along this side of the lagoon the inner margin of the lagoon reef does not drop steeply to the floor of the lagoon, as it does on the east side, but slopes down to a terrace that runs along the reef, and it is only on the inner side of this terrace that the reef drops sharply to the lagoon floor. Opposite Maradu this terrace has a width of about 30 yards and lies at a depth of 2 or 3 fathoms. So far as I could see, the terrace consists in the main of patches of live coral with a sandy floor between. Darwin (1889, p. 140) has called attention to the presence of such ledges on the lagoon side of the reef in certain atolls, and he explains them by the supposition that the atoll has at one time or another subsided too rapidly for the upward growth of the coral to counteract the downward movement, and that, in consequence, the old rim has been killed off and a new rim has grown up, leaving the terrace to denote the original level of the old rim. Without denying the possibility of such an explanation in certain cases, it seems impossible to apply it to the present instance because, as this terrace is only present in one section of the lagoon rim, we should have to suppose that there had been unequal subsidence in the different parts of the same atoll. The true explanation of the terrace is, I think, to be found in its situation on the south-west side of the lagoon ; during the growth of any reef a talus slope is gradually formed along its foot, and on the south-west side of the lagoon its formation will have been materially assisted by the destructive action of waves in this section of the reef, to which I have already alluded, as well as by deposition of sand and debris that is swept over from the outer reef platform. I have already (*vide supra*, p. 81 *et seq.*) shown that a considerable amount of erosion is, and has been, going on in the islands of the reef flat on this western side of the atoll, and the bulk of the products of this erosion appears to be swept through the channel between Hankadu and Abuhera Islands, though some, and possibly a considerable amount, passes between Maradu and Hankadu. With the single exception of the somewhat tortuous channel between Midu and Heratera, at the north-east corner of the lagoon, there is no channel on the east side through which there is a continuous flow of water from the outer to the inner reef flat and so to the lagoon at all states of the tide, whereas on the south-west side this is going on through all the channels ; at the same time the water on the outer reef flat is heated up to a considerable extent during low tide, and as the tide rises, this is swept through the channels on to and beyond the inner reef flat. To this action I attribute the wide interval in the lagoon reef that occurs opposite the gap between Hankadu and Abuhera Islands ; here the floor of the lagoon shoals gradually upwards to the sand-bar that connects the two islands on their lagoon sides, and the bottom consists entirely of sand dotted over with clumps of stag's horn coral, which, as I have already mentioned, appears to be the only type of coral that can maintain its existence on a sandy bottom, such as that which we are considering. Some of the sand is doubtless deposited on the inner reef flat, and it is to this that I attribute the almost complete disappearance of the boat-channel in this region ; but much of it is doubtless swept on into the lagoon, where it will serve to augment the talus slope, and in all probability has caused the appearance of shoal patches, one of which is shown on Moresby's chart opposite the middle of Maradu Island.

In the north-west corner of the lagoon the reef is fairly continuous, and shuts off an area of deep water near the village that is situated at the north end of Hitadu. It seems likely that in this area the growth of coral is extending. Moresby, in his original chart, shows the north-west area as open, with a depth of water of 5 to 10 fathoms ; but at the

time that Stanley Gardiner visited the atoll there seems to have been some considerable change, for he remarks (1903, p. 319) that " the upper part is a fairly clear basin, covered on the bottom with muddy sand. Towards its mouth, where it opens into the lagoon, these coral heads stud the whole surface, arising perpendicularly—perhaps overhanging at the top—from 10 fathoms or even deeper. Many of the knobs have grown together, so that a passage to the head of the bay is at the present time difficult for a vessel of any size, if not impossible ". At the time of my visit, so far as I could discover, there was only a single passage, marked by poles stuck in the bottom, through which a dhow could pass ; Certainly all dhows, when approaching this village at the head of the island, made use of this channel. The whole of the rest of the mouth of the bay is occluded by reefs.

THE LAGOON.

Moresby, in his original chart, shows a maximum depth of water in the lagoon of 39 fathoms in the north-east part ; he also records the presence of six shoal patches ; of these, three are situated in a triangle near the centre of the lagoon, one lies close to the reef on the east side of the south-east entrance, one near the lagoon reef on the west side, opposite Maradu Island, and finally a shoal patch in the north of the lagoon close to the isolated part of the reef between the two northern entrances.

In 1900 a series of soundings were taken by Forster Cooper, and the results that he obtained have been summarized by Stanley Gardiner as follows : " Making every allowance for the possibility that the soundings may have been too low—of which, nevertheless, there was no indication—the greatest depth obtained by my companion was 32 fathoms, where 36 fathoms ought to have been found. Where 39 fathoms are charted, only 31 fathoms were obtained. Isolated soundings may mean nothing on account of difficulty of fixation—in this atoll intensified by considerable changes in the land. Eliminating all but the most careful observations—many having been taken when dredging—23 are left, all of which show a decrease in depth of from 1 to 8 fathoms, the general reduction being 2 or 3 fathoms." From this evidence Stanley Gardiner concluded that the lagoon was silting up.

The average depth of water in the lagoon, excluding the shoal areas to the north-east and north-west, is, according to Moresby's chart, some 24·4 fathoms ; Forster Cooper's soundings give an average depth of only 21·5 fathoms. But the average depth, as shown by both Forster Cooper's soundings and ours together works out at 24·5 fathoms, which is almost exactly the same as that obtained by Moresby a hundred years earlier, so that on the whole it would appear probable that conditions in the lagoon are more or less stationary, though it is possible that under the influence of storms and the consequent increase in the currents and waves in the lagoon there may be a certain amount of movement of sediment from one part to another, resulting in an apparent increase of depth in some areas and a corresponding decrease in others.

Acting on the assumption that there has been little or no change in the depths, I have taken the chart published by the Admiralty and that given by Stanley Gardiner and have superposed these, and from the depths as given I have drawn the contour lines corresponding to the 20- and 30-fathom depths. The result is given in Text-fig. 1. From this it becomes quite evident that it is incorrect to speak of the lagoon having a flat floor. The distance of the 20-fathom contour from the edge of the lagoon reef varies enormously in different parts of the lagoon circumference ; this is particularly evident in the

northwest area, where there is an area of "foul ground" thickly dotted over with coral heads, and again in the eastern part of the lagoon, opposite the middle and south end of Putali Island. In this latter area the inward sweep of the 20-fathom contour line is in all probability correlated with the erosion that, as we have seen, is going on along the southern end of Midu-Huludu Island and the northern end of Putali, and that has formed the wide bay on the seaward side of these two islands; the sand and silt derived from this erosion is being swept, under the influence of the north-east monsoon, through the gap between these islands, and is then carried to the south-west, and is probably being deposited on the lagoon floor in the area immediately to the west of Putali Island. The 30-fathom contour line clearly indicates that there are two deep areas in the lagoon, in each of which water of a depth of 36 fathoms has been found. In the south-west half of the lagoon this deep area is comparatively small, but in the north-east area the deep portion is much larger and extends close up to the lagoon reef in the region where the anchorage is shown on the Admiralty Chart, 34 fathoms having been obtained close to the lagoon reef. The central part of the lagoon, where a group of three shoals are indicated on the chart, intervenes between these two deep regions, and it seems probable that this shallower belt, with the deep areas on each side of it, is correlated with the currents of water that enter the lagoon through the two sets of entrance channels on the north and south sides of the atoll.

According to Stanley Gardiner (1903, p. 319), "the bottom of the lagoon was found by my companion, Mr. Forster Cooper, to be covered with rubble and sand, one small patch of mud only existing at 27 fathoms to the head of the north-east horn. . . . Sedentary, and indeed all other organisms were on this class of bottom singularly scarce." This comparative scarcity of the fauna of the lagoon floor has been noticed and commented on by almost every observer who has studied these and similar atolls; and it is difficult to understand why coral does not and apparently cannot grow up from the floor of such a lagoon. During our visit a haul of the large grab was made in the north-east corner of the lagoon and a good sample of the bottom was obtained. This consisted of a fine cream-coloured mud that possessed a distinct odour of sulphuretted hydrogen, and a subsequent chemical examination showed that this gas was present to the extent of at least 4·9 mgrm. per litre of the occluded water, after this had been aspirated off from the sample. The mere action of aspirating off the water must have reduced the amount of gas originally present, so that it is justifiable to conclude that at least 5 mgrm. of the gas per litre were present *in situ*. The presence of this gas in such quantity may well prove to be distinctly adverse to coral growth or to the existence of other forms of animal life; but this is a problem that must await further researches.

BIBLIOGRAPHY.

Agassiz, A. 1903. The Coral Reefs of the Maldives. Bull. Mus. Comp. Zool. Harvard, XXIX.

Coral Reef Committee of the Royal Society. 1904. The Atoll of Funafuti.

Darwin, C. 1889. The Structure and Distribution of Coral Reefs (Third Edition). London: John Murray.

—— 1897. A Naturalist's Voyage round the World (1897 edition). London: John Murray.

Farquharson, W. I. 1936. John Murray Expedition, Scientific Reports, I, No. 2, Topography.

Gardiner, J. Stanley. 1903. The Fauna and Geography of the Maldive and Laccadive Archipelagos, I. (University Press, Cambridge.)

—— 1906. *Op. cit.*, II.

Murray, Sir J. 1913. The Ocean. Home University Library of Modern Knowledge. London.

Oldham, C. F. 1895. Topography of the Arabian Sea in the Neighbourhood of the Laccadives; (ii) The Physical Features of Some of the Islands. Journ. Asiatic Soc. Bengal, LXIV, part 2.

DESCRIPTION OF PLATE I.

Fig. 1.—The buttress and fissure zone on the N.E. side.

Fig. 2.—The outer reef flat and the S.E. part of Midu-Huludu Island.

Fig. 1.

Fig. 2.

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DESCRIPTION OF PLATE II.

FIG. 1.—Marine erosion on the north-east side of Addu Atoll, between Huludu and Putali.

FIG. 2.—The channel between Huludu and Putali Islands.

FIG. 3.—The boulder zone on the south-west side.

FIG. 1.

FIG. 2.

FIG. 3.

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DESCRIPTION OF PLATE III.

Fig. 1.—" Coral horses " on the western outer reef flat.
Fig. 2.—The north-east part of Putali Island.

FIG. 1.

FIG. 2.

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DESCRIPTION OF PLATE IV.

Fig. 1.—The inner face of the seaward rampart, Putali Island.

Fig. 2.—The lagoon beach of Putali Island.

Fig. 3.—Putali Island. Outcrop of sandstone on the lagoon beach.

FIG. 1.

FIG. 3.

FIG. 2.

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DESCRIPTION OF PLATE V.

Fig. 1.—One of the fresh-water pools on Putali Island.

Fig. 2.—A brackish-water lake : the northernmost of the outer series of Putali Island.

Fig. 1.

Fig. 2.

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DESCRIPTION OF PLATE VI.

Fig. 1.—The reef flat and outer beach of Mulikadu Island.
Fig. 2.—The coral breccia exposure on the west side of Abuhera.

FIG. 1.

FIG. 2.

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DESCRIPTION OF PLATE VII.

Fig. 1.—The lagoon reef on the north-east side.

Fig. 2.—A near view of coral colonies on the north-east reef.

FIG. 1.

FIG. 2.

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DESCRIPTION OF PLATE VIII.

Fig. 1.—The inner margin of the lagoon reef on the south-west side.
Fig. 2.—Coral on the inner reef flat on the south-west side.

FIG. 1.

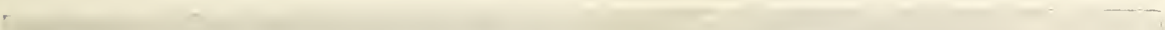

FIG. 2.

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A REPORT ON THE VALUES OF GRAVITY IN THE MALDIVE AND LACCADIVE ISLANDS

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E. A. GLENNIE, LT.-COL., R.E., D.S.O.,
Geodetic Branch, Survey of India.

WITH ONE PLATE AND FOUR CHARTS

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WITH ONE PLATE AND FOUR CHARTS.

1. Foreword.—For four weeks in March and April, 1934, No. 14 Party, Survey of India, collaborated with the John Murray Expedition, making gravity observations at eight places in the Maldive Islands, and at one station, Minikoi (Minicoy), in the Laccadive Islands.

The following account is largely a reprint from the Survey of India Geodetic Report, 1934, Chapter III, with the addition of appendices giving descriptions of the gravity stations, a summary of the Hayford reductions and details of density determinations from the cores of the Funafuti boring.

Gravity results in the Maldive Islands should be considered in relation to those obtained on the west coast of India, which are discussed more fully in Geodetic Report 1934.

2. Gravity Results.—These are shown in Tables I and II and in Pl. I, fig. 2. Their relation with India is shown in Charts I to IV. Descriptions of stations are given in Appendix I.

3. Hayford Reductions.—In addition to the depths given in the latest Admiralty Charts and in the Prince of Monaco's ocean maps, those obtained by the continuous echo-sounding apparatus on H.E.M.S. "Mabahiss" have been used. The Expedition made special runs in order to obtain the profile of the bank on the east and west sides of the archipelago. These are shown in Pl. I, fig. 1. A smooth curve giving the average profile was drawn from these and employed where other depth data were not available. The sites of the gravity stations were always on the lagoon side of the island, so topographical changes in the nearer zones were small. In view of the very considerable amount of depth data available the Hayford reduction work may be considered free from appreciable error.

The depth estimations and Hayford reductions for Dr. Vening Meinesz's submarine

gravity station near Minikoi have been entirely redone; the final Hayford correction amounted to + 0·0266 g. as compared with + 0·0260 g. obtained by the United States Coast and Geodetic Survey—a close agreement which may be considered very satisfactory.

The Hayford reduction zones and tables given in Survey of India Professional Paper XV have been employed throughout for this work.

4. Discussion of Results.—The large negative anomalies in the Maldives are remarkable; these increase towards the central meridian of the Archipelago. Precisely the opposite is the case at Minikoi, for the crustal warp anomaly is positive on land and reduces to zero at the sea station to the west, thus indicating a tectonic condition under the Laccadives apparently opposite to that under the Maldives.

From the gravity and deflection observations on the west coast of India it is known that a positive area flanks the coast as far south as Mangalore; if this is extended to Minikoi it is significant that a line drawn from Minikoi to Mangalore will skirt the southern margin of Kalpeni and Androth Islands, Ellicalpeni Bank and other shallow soundings. It seems therefore a plausible deduction that the great positive upwarp off the Bombay coast runs south under the Laccadives to Minikoi, while the flanking depression of the crust on its east side continues out to sea south of Mangalore to the line of the Maldives, where a continental fragment of the crust has been crushed in the downwarp or submerged.

This conclusion is supported by V. Meinesz's work in the Java Sea. Sumatra and Java are flanked on the south and west by a great band of negative anomalies. This band persists whether its line is marked by islands or by deep sea. Over Sumatra and Java large positive gravity anomalies are found, but further east the high positive area underlies the deep Banda Sea, while the negative band continues along the curve of the islands to Coram.

Evidently the superficial conditions are incidental only; it is to the deeper warpings of the crust that the greater part of the anomalies must be referred.

The Admiralty Charts also show a marked difference between the Laccadive Islands and the Maldive Islands. Instead of the striking linear arrangement of the Maldives, with great atolls ten to twenty miles across, the Laccadives show a confused medley of small islands, reefs and banks.

Though the Laccadive Islands are believed to overlie an upwarped area of the crust, a small amount of recent submergence is not excluded. The original upwarp, if associated with the Aravalli upheaval, may have occurred in geologically remote times, but any subsequent contrary movement has been much less than the original upwarp.

5. The Formation of the Maldive Islands.—The formation of the Maldive Islands will be considered first with reference to the isostatic anomalies and secondly in the light of the crustal warp hypothesis.

(a) *Isostatic anomalies.*—In Fadiffolu Atoll the two stations Difuri and Kānifuri are at the extreme east and west margins of the atoll and there are no stations in the middle of the lagoon. In South Mālosmadulu Atoll, Fonimagudu is on the eastern edge and Turādu on the western edge, while Māmādu and Mandu are in the lagoon. All the anomalies are negative, and the largest anomalies are at the two stations in the lagoon.

In the Hayford corrections no allowance has been made for the low density of the

coral rock, since its thickness is unknown, and it is at the stations in the lagoon that the error on this account would be greatest.

Considering only the four stations in South Mālosmadulu Atoll, assume 3000 ft. thickness of coral rock, density 1·8, the deficiency in mass due to this low density being uncompensated. Changing the topographical corrections accordingly, the following result is obtained :

	$g-\gamma_C$ (uncorrected).	$g-\gamma_C$ (corrected for coral 3000 ft. thick).
Fonimagudu	− 73 mgal.	− 47 mgal.
Māmādu	− 81 ,,	− 49 ,,
Mandu	− 77 ,,	− 45 ,,
Turādu	− 74 ,,	− 45 ,,

The correction has therefore largely removed the discrepancy between the lagoon stations and the marginal stations.*

The same assumptions applied to the Difuri and Kānifuri correction give the following results :

	$g-\gamma_C$ (uncorrected).	$g-\gamma_C$ (corrected).
Difuri	− 66	− 36
Kānifuri	− 71	− 44

Kānifuri therefore falls into line fairly well, but Difuri is exceptional.

Considering the five accordant stations, the mean "corrected" anomaly is − 46 mgals., and assuming that this anomaly is due to an additional thickness of coral, density 1·8, again with the defect uncompensated, 4000 ft. additional thickness of coral is required. According to the usual explanation of the formation of coral islands over a subsiding land mass, however, isostatic adjustment is given as the cause of subsidence. Defect of mass is, therefore, inadmissible, so compensation must be allowed for. With compensation of the light coral rock an additional 5000 ft. thickness is required.

The isostatic anomalies therefore if solely due to the light coral rock imply a thickness of 7000 ft. of coral *uncompensated* or 12,000 ft. *compensated* ; 12,000 ft. thickness brings the coral deeper than the immediately surrounding ocean, a result which is only consistent with isostatic adjustment if the original land mass or bank on which the coral was formed was an upwarp of the ocean floor and not a continental relic of normal sial.

The density (1·8) which has been assumed for the coral is probably the lowest permissible ; computation with higher densities would yield greater thicknesses of coral.

These calculations are based on the Helmert gravity formula of 1901 ; if the Bowie formula or the International gravity formula of 1930 were used, the computations would require very much greater thicknesses of coral. The formula based on the Survey of India spheroid which is used for the $g-\gamma_F$ anomalies would give better results, since it reduces the Helmert negative anomalies over the Maldives by 18 mgals. The total

* A coral thickness of 3000 ft. gives the best result, since the discrepancy is larger if a thickness of 2500 ft. or 3500 ft. is assumed.

resulting thickness of coral (density 1·8) is then about 5000 ft. uncompensated or 9000 ft. compensated.

The employment of this same gravity formula in India without additional corrections would be unsatisfactory. The negative anomaly in South India would indeed be reduced, but this apparent advantage would be offset by a greatly increased area of very high positive anomalies in the northern part of the Peninsula. The use of this formula for the adjacent Maldive region without additional corrections is, therefore, hardly justified.

The conclusion, therefore, from this investigation of the isostatic anomalies is that, if the isostatic anomalies are due to local, superficial anomalies of density, the Maldive Islands mark the original site of an oceanic ridge, *not a continental block*, which has since sunk down under isostatic adjustment. Under Minikoi is part of the same ridge not yet isostatically adjusted.

(b) *Crustal warping.*—According to the hypothesis of crustal warping, gravity anomalies are mainly due to the up and down warpings of the lower layers of the crust. These tend to balance out, and over a very wide area equilibrium is reached very closely. This is a necessary result of the working of the ordinary laws of mechanics and of strength of materials.* Hence the Hayford method of computation provides an easy means of allowing for this general equilibrium. When computing the $g-\gamma_F$, or crustal warp, anomaly, Hayford compensation is assumed to be lacking over an area of about 1600 square miles immediately surrounding the station. This anomaly is then assumed to give a measure of the underlying crustal warping, combined with the effect due to local departures of the superficial strata from normal density. In India there appears to be a general broad warping of the lower crustal layers superimposed on the more local warpings. In order to give prominence to the local warpings and so to bring out more clearly the local tectonic structure, a " hidden range " correction is applied to the crustal warp anomalies, which is intended to remove the effects of the general warping. In the Maldive Islands there is no reason to assume any general warping of this nature, nor is it likely. The crustal warp anomalies, therefore, contain no " hidden range " correction.

If the underlying rock has a smooth level surface, which is not improbable, the argument used for the extra large isostatic anomalies at the two lagoon stations holds good also for the $g-\gamma_F$ anomalies. In the table below are given (1) the isostatic anomaly, $g-\gamma_{CS}$, using the gravity formula on which the crustal warp anomalies are based, (2) the crustal warp anomaly $g-\gamma_F$, and (3) $g-\gamma_F$ corrected for the effect of 3000 ft. of coral, density 1·8.

	$g-\gamma_{CS}$.	$g-\gamma_F$.	$g-\gamma_F$ (corrected for 3000 ft. of coral).
Difuri . . .	− 48 mgals.	− 28 mgals.	+ 2 mgals.
Kānifuri . . .	− 53 ,,	− 43 ,,	− 15 ,,
Fonimagudu . .	− 55 ,,	− 48 ,,	− 23 ,,
Māmādu . . .	− 63 ,,	− 58 ,,	− 26 ,,
Mandu . . .	− 59 ,,	− 53 ,,	− 21 ,,
Turādu . . .	− 56 ,,	− 39 ,,	− 10 ,,

* See " The Hypothesis of Isostasy ", Dr. J. de Graaff Hunter, ' Monthly Notices of R.A.S., Geoph. Suppt.', January, 1932.

Interpreted according to the previous explanation, the $g-\gamma_F$ anomalies indicate a downwarp.* It can be assumed that the coral has formed over the top of a block of sial of normal density which has foundered in this downwarp. The small outer anomalies show the effect of flanking upwarps. The greatest anomaly may be taken as indicating the amount of downwarp. Table III in Professional Paper No. 27 gives a means of computing the approximate depth of the downwarp.

The following assumptions may be made :

(1) No thickness of coral—an unreal assumption, since there is no rock to be seen on the islands other than coral and the purely superficial beach or island sandstone.

(2) Three thousand feet of coral.

(3) Downwarping equal to the thickness of coral—an interesting assumption, which implies that coral formation has kept pace with subsidence if the original land was nearly at sea level.

Of course subsidence may not be quite the same as the downwarping ; there might be a sagging of the block in the middle, or, on the other hand, a crushing upwards of the block.

The table below gives results according to the above three assumptions :

Computed Depth of Downwarping.

Assumed thickness of coral. (Feet.)	Density 1·8. (Feet.)	Density 2·2. (Feet.)
Nil	17,000	17,000
3000	7500	†
4200	4200	†
6500	†	6500

Referring to the seaward profile shown in Pl. I, fig. 1, there appears to be a definite change of slope about 3 sea miles out. If the steeper inner slope is the talus slope of coral debris outside the atoll, then the outer, more gentle slope may be assumed to be an uncovered portion of the underlying sial block. Continuing this slope inwards, it rises to a depth of about 700 fathoms below the atoll, so that a capping of about 4000 ft. of coral is required.

Plainly the crustal warp anomalies alone cannot yield a definite result for the thickness of the coral, but the conclusion drawn from them is that the Maldive Islands overlie an area where a block of sial has subsided as a result of the downwarping of the lower crustal layers. Whether this conclusion or that derived from the isostatic anomalies is to be preferred is a matter for argument in the light of the various theories of coral island formation, continental drift and so on.

* The crustal warp hypothesis assumes the warping of an intermediate layer underlying the light outer granitic layer. If the upper layer alone has been downfolded, then a much greater amount of downfolding is required to explain the negative anomalies.

† Not computed.

TABLE I.—*Gravity Observations.*

No.	Station.	Date.	Height.	Latitude.	Longitude.	g.	p.e.
			ft.	° ′ ″	° ′ ″	gal.	mgal.
333	Midu . . .	22.iii.34	5	S0 35 54	E73 10 45	978·105	±0·9
334	Timārifuri . .	24.iii.34	4	N2 13 12	E73 09 18	978·129	2·1
335	Difuri . . .	29.iii.34	4	N5 23 36	E73 38 00	978·122	1·4
336	Kānifuri . .	31.iii.34	4	N5 22 12	E73 19 12	978·107	1·2
337	Fonimagudu .	2.iv.34	4	N5 15 54	E73 10 24	978·109	1·2
338	Māmādu . .	4.iv.34	4	N5 13 30	E73 03 36	978·095	1·2
339	Mandu . .	5.iv.34	4	N5 11 30	E72 58 00	978·102	1·0
340	Turādu . .	7.iv.34	5	N5 02 42	E72 48 42	978·109	1·0
341	Minikoi . .	10.iv.34	6	N8 19 03	E73 03 51	978·221	1·0
	Dr. V. Meinesz's sea station	22.xi.23	0	N8 06	E72 48	978·116	..

TABLE II.—*Gravity Anomalies, in milligals.*

No.	Helmert's formula of 1901.			International formula of 1930.	Survey of India formula.	
	$g-\gamma_{A}$.	$g-\gamma_{B}$.	$g-\gamma_{CH}$.	$g-\gamma_{CI}$.	$g-\gamma_{CS}$.	$g-\gamma_{F}$.
333	+ 74	+ 85	− 87	− 106	− 70	− 46
334	+ 92	+ 65	− 76	− 95	− 59	− 41
335	+ 46	+ 57	− 66	− 85	− 48	− 28
336	+ 32	+ 38	− 71	− 90	− 53	− 43
337	+ 35	+ 33	− 73	− 92	− 55	− 48
338	+ 22	+ 24	− 81	− 100	− 63	− 58
339	+ 30	+ 31	− 77	− 96	− 59	− 53
340	+ 40	+ 48	− 74	− 93	− 56	− 39
341	+ 84	+ 115	− 30	− 49	− 12	+ 19
V. M.'s station	− 25	+ 101	− 52	− 71	− 34	± 0

Helmert's formula of 1901 $\gamma_0 = 978{\cdot}030\ (1 + 0{\cdot}005\ 302 \sin^2 \phi - 0{\cdot}000\ 007 \sin^2 2\phi)$ gal.
International formula of 1930 $\gamma_0 = 978{\cdot}049\ (1 + 0{\cdot}005\ 288 \sin^2 \phi - 0{\cdot}000\ 006 \sin^2 2\phi)$.
Survey of India formula $\gamma_0 = 978{\cdot}013\ (1 + 0{\cdot}005\ 234 \sin^2 \phi - 0{\cdot}000\ 006 \sin^2 2\phi)$.
$g-\gamma_A$ = Free air anomaly; $g-\gamma_B$ = Bouguer anomaly; $g-\gamma_C$ = isostatic anomaly; $g-\gamma_F$= crustal warp anomaly.

LIST OF CHARTS.

CHART I.—Gravity anomalies (Hayford); contours showing $g-\gamma_{CH}$.

CHART II.—Gravity anomalies; contours showing $g-\gamma_F$.

CHART III.—Gravity anomalies; contours showing $g-\gamma_{CI}$.

CHART IV.—Crustal structure lines.

APPENDIX I

DESCRIPTION OF GRAVITY STATIONS.

At all stations, except Mandu, the pendulum apparatus was set up in two small tents placed end-to-end. These consisted of a light 2-fly tent, 8 ft. by 8 ft. in size, and a single fly *shouldāri* 10 ft. by 8 ft. in size. In most of the islands the vegetation is very dense, and no space could have been found to pitch a large tent without a great deal of clearing. The height was obtained by clinometer from the lagoon water-level at half tide.

STATION No. 333.

MALDIVE ISLANDS.

Midu (North-east Side of Addu Atoll).

The gravity station is sited 35 yds. from the lagoon shore and about $\frac{1}{4}$ mile south-west of Midu village, from which it is separated by a tidal creek.

An Admiralty Bench-mark is 27 yds. south of the station—good water obtainable.

STATION No. 334.

MALDIVE ISLANDS.

Timārifuri (South of Kolumadulu Atoll).

The gravity station is sited close to the lagoon shore on the west side of a small uninhabited island north of Timārifuri.

STATION No. 335.

MALDIVE ISLANDS.

Difuri (East of Fadiffolu Atoll).

The gravity station is sited close to the lagoon shore on the west side of the uninhabited island of Difuri, about one mile from the south end of the island. Good water is obtainable from a *pakka* well.

STATION No. 336.

MALDIVE ISLANDS.

Kānifuri (West of Fadiffolu Atoll).

The gravity station is sited close to the lagoon shore on the north side of the uninhabited island of Kānifuri.

STATION No. 337.

Maldive Islands.

Fonimagudu (East of South Mālosmadulu Atoll).

The gravity station is sited close to the lagoon shore on the west side of the small uninhabited island of Fonimagudu. This island is about 5 miles south-east of Kumādu and 10 miles north-east of Duravandu. Good water is obtainable from two *kacha* wells.

STATION No. 338.

Maldive Islands.

Māmādu (in lagoon of South Mālosmadulu Atoll).

The gravity station is sited close to the shore on the south side of the island, which is uninhabited. The island is locally called Modu.

STATION No. 339.

Maldive Islands.

Mandu (in lagoon of South Mālosmadulu Atoll).

The gravity station is sited close to the shore on the south side of the island, which is uninhabited.

The pendulum apparatus was installed in a small thatched shelter, about 12 ft. by 10 ft. in size, found in the island.

STATION No. 340.

Maldive Islands.

Turādu (West of South Mālosmadulu Atoll).

The gravity station is sited in a clearing just south of the village.

STATION No. 341.

Laccadive Islands.

Minikoi.

The gravity station is sited close to the lagoon shore, about 250 yds. from the north end of the island.

APPENDIX II

MEAN CORRECTIONS TO γ_0 FOR TOPOGRAPHY AND ISOSTATIC COMPENSATION FOR SEPARATE ZONES.

Zone.	Average height (ft.).	Topog. (mgals.).	Comp. (mgals.).	Topog. and comp.	Average height (ft.).	Topog. (mgals.).	Comp. (mgals.).	Topog. and comp.
	Station No. 333.				Station No. 334.			
A	+ 5	+ 0·10	0	+ 0·10	+ 4	+ 0·08	0	+ 0·08
B	+ 2	+ 0·04	0	+ 0·04	+ 2	+ 0·02	0	+ 0·02
C	− 3	0	0	0	− 1	0	0	0
D	− 4	− 0·01	0	− 0·01	− 7	− 0·01	0	− 0·01
E	− 6	− 0·01	0	− 0·01	− 14	− 0·01	0	− 0·01
F	− 10	0	0	0	− 180	− 0·16	+ 0·03	− 0·13
G	− 66	− 0·01	+ 0·01	0	− 454	− 0·28	+ 0·07	− 0·21
H	− 133	− 0·01	+ 0·02	+ 0·01	− 716	− 0·38	+ 0·10	− 0·28
I	− 216	− 0·02	+ 0·06	+ 0·04	− 999	− 0·74	+ 0·28	− 0·46
J	− 640	− 0·13	+ 0·36	+ 0·23	− 1,633	− 1·48	+ 0·91	− 0·51
K	− 2,462	− 1·22	+ 1·99	+ 0·77	− 2,423	− 1·82	+ 1·96	+ 0·14
L	− 4,139	− 1·72	+ 4·23	+ 2·51	− 3,239	− 1·64	+ 3·30	+ 1·66
M	− 6,346	− 2·78	+ 11·81	+ 9·03	− 3,998	− 1·75	+ 7·41	+ 5·66
N	− 7,096	− 2·13	+ 16·70	+ 14·57	− 4,661	− 1·30	+ 10·91	+ 9·61
O	− 8,940	− 3·06	+ 34·59	+ 31·53	− 6,903	− 2·16	+ 26·59	+ 24·43
P	−10,060	− 2·74	+ 33·38	+ 30·64	− 7,506	− 1·80	+ 24·74	+ 22·94
18	−10,070	..	..	+ 6·21	− 8,850	..	..	+ 5·45
17	−10,440	..	..	+ 6·45	− 9,370	..	..	+ 5·79
16	−10,910	..	..	+ 6·77	−10,040	..	..	+ 6·22
15	−11,600	..	..	+ 7·24	−10,810	..	..	+ 6·73
14	−12,150	..	..	+ 7·62	−11,400	..	..	+ 7·16
13	−12,240	..	..	+ 12·02	−11,970	..	..	+ 11·75
12	−11,590	..	..	+ 7·11	−11,870	..	..	+ 7·28
10, 11	..	..	..	+ 9·90	..	..	..	+ 9·30
7 to 9	..	..	..	+ 6·10	..	..	..	+ 5·85
1 to 6	..	..	..	+ 1·38	..	..	..	+ 1·40
Total	. . . . .			+ 160·25	. . . . . .			+ 129·80
	Station No. 335.				Station no. 336.			
A	+ 4	+ 0·08	0	+ 0·08	+ 4	+ 0·08	0	+ 0·08
B	0	0	0	0	+ 3	+ 0·03	0	+ 0·03
C	− 1	− 0·01	0	− 0·01	− 3	− 0·01	0	− 0·01
D	− 1	− 0·01	0	− 0·01	− 3	− 0·01	0	− 0·01
E	− 12	− 0·01	0	− 0·01	− 17	− 0·01	0	− 0·01
F	− 35	− 0·01	0	− 0·01	− 315	− 0·45	+ 0·04	− 0·41
G	− 173	− 0·06	+ 0·03	− 0·03	− 549	− 0·41	+ 0·08	− 0·33
H	− 340	− 0·10	+ 0·05	− 0·05	− 1,202	− 0·62	+ 0·17	− 0·45
I	− 790	− 0·45	+ 0·22	− 0·23	− 1,885	− 0·82	+ 0·40	− 0·42
J	− 1,835	− 1·67	+ 1·02	− 0·65	− 1,606	− 0·89	+ 0·90	+ 0·01
K	− 3,182	− 2·42	+ 2·57	+ 0·15	− 1,685	− 0·55	+ 1·36	+ 0·81
L	− 3,812	− 1·81	+ 3·90	+ 2·09	− 1,783	− 0·33	+ 1·82	+ 1·49
M	− 4,537	− 1·88	+ 8·41	+ 6·53	− 1,619	− 0·27	+ 2·98	+ 2·71
N	− 5,192	− 1·33	+ 12·16	+ 10·83	− 2,670	− 0·51	+ 6·22	+ 5·71
O	− 4,547	− 1·23	+ 17·41	+ 16·18	− 4,228	− 1·00	+ 16·17	+ 15·17
P	− 6,210	− 1·39	+ 21·09	+ 19·70	− 6,350	− 1·46	+ 20·88	+ 19·42
18	− 6,870	..	..	+ 4·23	− 7,330	..	..	+ 4·52
17	− 7,400	..	..	+ 4·56	− 7,990	..	..	+ 4·92
16	− 8,200	..	..	+ 5·07	− 8,840	..	..	+ 5·47
15	− 9,040	..	..	+ 5·62	− 9,450	..	..	+ 5·88
14	− 9,660	..	..	+ 6·05	− 9,970	..	..	+ 6·25
13	−10,500	..	..	+ 10·29	−10,600	..	..	+ 10·40
12	−10,170	..	..	+ 6·22	−10,340	..	..	+ 6·32
10, 11	..	..	..	+ 8·73	..	..	..	+ 8·73
7 to 9	..	..	..	+ 5·37	..	..	..	+ 5·38
1 to 6	..	..	..	+ 1·42	..	..	..	+ 1·42
Total	. . . . .			+ 113·45	. . . . . .			+ 103·09

Zone.	Average height (ft.).	Topog. (mgals.).	Comp. (mgals.).	Topog. and comp.	Average height (ft.).	Topog. (mgals.).	Comp. (mgals.).	Topog. and comp.
	Station No. 337.				Station No. 338.			
A	+ 4	+ 0·08	0	+ 0·08	+ 4	+ 0·08	0	+ 0·08
B	0	+ 0·01	0	+ 0·01	0	0	0	0
C	− 2	− 0·01	0	− 0·01	− 8	− 0·01	0	− 0·01
D	− 4	− 0·01	0	− 0·01	− 16	− 0·01	0	− 0·01
E	− 38	− 0·02	0	− 0·02	− 130	− 0·07	+ 0·01	− 0·06
F	− 229	− 0·26	+ 0·03	− 0·23	− 135	− 0·04	+ 0·02	− 0·02
G	− 461	− 0·27	+ 0·07	− 0·20	− 124	− 0·02	+ 0·01	− 0·01
H	− 597	− 0·20	+ 0·08	− 0·12	− 112	− 0·01	+ 0·02	+ 0·01
I	− 799	− 0·31	+ 0·22	− 0·09	− 118	− 0·01	+ 0·03	+ 0·02
J	− 1,109	− 0·45	+ 0·66	+ 0·17	− 121	− 0·01	+ 0·07	+ 0·06
K	− 1,276	− 0·32	+ 1·03	+ 0·71	− 238	− 0·01	+ 0·19	+ 0·18
L	− 1,471	− 0·23	+ 1·50	+ 1·27	− 741	− 0·04	+ 0·76	+ 0·72
M	− 1,340	− 0·18	+ 2·47	+ 2·29	− 1,158	− 0·14	+ 2·13	+ 1·99
N	− 1,559	− 0·18	+ 3·62	+ 3·44	− 2,350	− 0·40	+ 5·47	+ 5·07
O	− 4,219	− 1·01	+ 16·14	+ 15·13	− 4,188	− 1·06	+ 16·02	+ 14·96
P	− 6,384	− 1·45	+ 20·49	+ 19·54	− 6,425	− 1·49	+ 21·13	+ 19·64
18	− 7,483	..	..	+ 4·61	− 7,660	..	..	+ 4·72
17	− 8,042	..	..	+ 4·96	− 8,184	..	..	+ 5·05
16	− 8,708	..	..	+ 5·38	− 8,798	..	..	+ 5·44
15	− 9,479	..	..	+ 5·90	− 9,575	..	..	+ 5·96
14	−10,008	..	..	+ 6·27	−10,145	..	..	+ 6·35
13	−10,746	..	..	+ 10·55	−10,802	..	..	+ 10·61
12	−10,343	..	..	+ 6·35	−10,447	..	..	+ 6·41
10, 11	..	..	..	+ 8·73	..	..	..	+ 8·73
7 to 9	..	..	..	+ 5·39	..	..	..	+ 5·39
1 to 6	..	..	..	+ 1·41	..	..	..	+ 1·41
Total .				+ 101·51				+ 102·69
	Station No. 339.				Station No. 340.			
A	+ 4	+ 0·08	0	+ 0·08	+ 5	+ 0·10	0	+ 0·10
B	0	0	0	0	+ 3	+ 0·04	0	+ 0·04
C	− 3	− 0·01	0	− 0·01	− 1	0	0	0
D	− 19	− 0·01	0	− 0·01	− 4	− 0·01	0	− 0·01
E	− 70	− 0·02	+ 0·01	− 0·01	− 10	− 0·01	0	− 0·01
F	− 100	− 0·02	+ 0·01	− 0·01	− 39	− 0·01	0	− 0·01
G	− 117	− 0·01	+ 0·02	+ 0·01	− 285	− 0·15	+ 0·04	− 0·11
H	− 126	− 0·01	+ 0·02	+ 0·01	− 443	− 0·15	+ 0·06	− 0·09
I	− 121	− 0·01	+ 0·03	+ 0·02	− 785	− 0·43	+ 0·22	− 0·21
J	− 136	− 0·01	+ 0·08	+ 0·07	− 1,499	− 1·08	+ 0·84	− 0·24
K	− 128	0	+ 0·10	+ 0·10	− 2,588	− 1·72	+ 2·09	+ 0·37
L	− 297	− 0·01	+ 0·30	+ 0·29	− 3,189	− 1·41	+ 3·25	+ 1·84
M	− 1,745	− 0·34	+ 3·22	+ 2·88	− 3,753	− 1·75	+ 6·95	+ 5·20
N	− 3,350	− 0·80	+ 7·82	+ 7·02	− 4,535	− 1·49	+ 10·61	+ 9·12
O	− 4,296	− 1·13	+ 16·43	+ 15·30	− 4,846	− 1·49	+ 18·78	+ 17·29
P	− 6,373	− 1·48	+ 20·96	+ 19·48	− 6,383	− 1·50	+ 21·01	+ 19·51
18	− 7,838	..	..	+ 4·83	− 8,008	..	..	+ 4·93
17	− 8,325	..	..	+ 5·14	− 8,550	..	..	+ 5·28
16	− 8,888	..	..	+ 5·49	− 9,033	..	..	+ 5·59
15	− 9,671	..	..	+ 6·01	− 9,754	..	..	+ 6·07
14	−10,281	..	..	+ 6·42	−10,450	..	..	+ 6·55
13	−10,858	..	..	+ 10·66	−10,958	..	..	+ 10·76
12	−10,550	..	..	+ 6·47	−10,633	..	..	+ 6·52
10, 11	..	..	..	+ 8·73	..	..	..	+ 8·73
7 to 9	..	..	..	+ 5·39	..	..	..	+ 5·40
1 to 6	..	..	..	+ 1·40	..	..	..	+ 1·40
Total .				+ 105·76				+ 114·02

Zone.	Average height (ft.).	Topog. (mgals.).	Comp. (mgals.).	Topog. and comp.	Average height (ft.).	Topog. (mgals.).	Comp. (mgals.).	Topog. and comp.
	Station No. 341.				Dr V. Meinesz's Sea Station.			
A	+ 5	+ 0·10	0	+ 0·10	− 6120	− 0·21	0	− 0·21
B	+ 4	+ 0·02	0	+ 0·02	− 6120	− 3·86	0	− 3·86
C	− 3	0	0	0	− 6120	− 7·70	+ 0·01	− 7·69
D	− 77	− 0·16	0	− 0·16	− 6120	− 13·75	+ 0·05	− 13·70
E	− 140	− 0·23	+ 0·01	− 0·22	− 6120	− 17·47	+ 0·12	− 17·35
F	− 656	− 1·43	+ 0·10	− 1·33	− 5970	− 24·56	+ 0·48	− 24·08
G	− 1485	− 1·99	+ 0·21	− 1·78	− 5970	− 14·18	+ 0·65	− 13·53
H	− 2517	− 2·67	+ 0·34	− 2·33	− 5970	− 9·10	+ 0·72	− 8·38
I	− 3504	− 4·91	+ 0·97	− 3·94	− 5970	− 9·98	+ 1·68	− 8·30
J	− 4715	− 6·33	+ 2·81	− 3·52	− 5970	− 8·70	+ 2·75	− 5·95
K	− 4892	− 3·81	+ 3·93	+ 0·12	− 5925	− 5·02	+ 4·75	− 0·27
L	− 6142	− 3·18	+ 6·28	+ 3·10	− 6000	− 2·90	+ 6·14	+ 3·24
M	− 6408	− 2·82	+ 11·93	+ 9·11	− 6100	− 2·55	+ 11·35	+ 8·80
N	− 6254	− 1·65	+ 14·68	+ 13·03	− 6425	− 1·78	+ 15·09	+ 13·31
O	− 6996	− 1·97	+ 26·93	+ 24·96	− 7075	− 1·99	+ 27·24	+ 25·25
P	− 7804	− 1·81	+ 25·69	+ 23·88	− 8425	− 2·00	+ 27·77	+ 25·77
18	− 8200	..	..	+ 5·05	− 8671	..	..	+ 5·32
17	− 8454	..	..	+ 5·21	− 8783	..	..	+ 5·41
16	− 8433	..	..	+ 5·21	− 8821	..	..	+ 5·45
15	− 8120	..	..	+ 5·04	− 8621	..	..	+ 5·35
14	− 7892	..	..	+ 4·92	− 8458	..	..	+ 5·27
13	− 7504	..	..	+ 7·35	− 7550	..	..	+ 7·68
12	..	..	..	+ 4·61	− 7884	..	..	+ 4·73
10, 11	..	..	..	+ 7·85	− 7696	..	..	+ 7·90
7 to 9	..	..	..	+ 4·90	..	..	..	+ 5·00
1 to 6	..	..	..	+ 1·43	..	..	..	+ 1·42
Total				+ 112·61				+ 26·58

APPENDIX III

An expedition, sent out by the Royal Society in 1896, made a boring in the coral island of Funafuti in the Pacific Ocean, to a depth of 1114 ft. The cores obtained from this boring are at the British Museum (Natural History), and appeared to be the only available source from which to form an estimate of the mean density of the coral formations in coral islands.

Mr. M. H. Hey kindly undertook to determine the densities of the cores. His remarks are given below. Commenting on these results, Prof. J. Stanley Gardiner writes as follows :

" The pieces taken are such as to give too high figures for each individual one if I read them aright. I think you would be absolutely safe to take 1·8, but of course you could go to extreme 2·0. I got a lot of similar determinations from coral island rocks made for me once and they were below 1·8".

Extract from letter from Mr. M. H. Hey, dated June 14th, 1934, Mineral Department, British Museum (Nat. Hist.).

" It is rather unfortunate that the quantity required should be the bulk densities as saturated with water. This cannot readily be accurately determined. I have proceeded as follows : 22 cores were selected from representative depths, weighed, measured carefully with the millimetre scale, and the volume calculated. The mean dry density* was so obtained, and from this and the known dolomite content the mean wet density† was calculated.

" The determinations were performed by Mr. S. E. Ellis of this Department under my direction. The probable accuracy of the data cannot exceed 0·05 and may not exceed 0·2. I should add that I am afraid the value of the results will be considerably reduced by the fact that a large percentage‡ of the cores are not solid, but consist of broken fragments. It would obviously be impossible to find the mean wet density of these disintegrating cores in their original state and I have not examined any of them. It is certain, however, that these cores which disintegrated must have been much more porous than those which did not, and would, therefore, have a considerably lower mean wet density. I should estimate the mean wet density of these cores which disintegrated at from 1·5 to 2·0, probably mostly between 1·8 and 2·0 ".

* *I. e.*, the mean density of the dry core as a whole, including the pores.
† *I. e.*, the mean density of the core with all the pores filled with water.
‡ Perhaps 30–50 % ; I have not counted them.

Number of core.	Approximate depth in feet.	Mean dry density in grammes per c.c.	Mean wet density in grammes per c.c.
3	3	2·02	2·28
15	15	2·52	2·60
55	64	2·24	2·42
94	82	2·26	2·43
141	160	2·33	2·47
175	200	1·96	2·24
All cores between 200 and 380 ft. disintegrated.			
205	380	2·40	2·52
216	435	2·44	2·54
229	452	2·62	2·66
258	512	2·28	2·44
294	552	2·14	2·35
304	598	1·68	2·06
335	652	2·01	2·28
363	695	1·57	2·00
41a	760	2·72	2·74
163a	810	2·47	2·58
254a	855	2·60	2·66
339a	898	2·50	2·60
431a	950	2·24	2·46
520a	1000	2·43	2·67
603a	1050	2·64	2·69
701a	1110	2·68	2·71

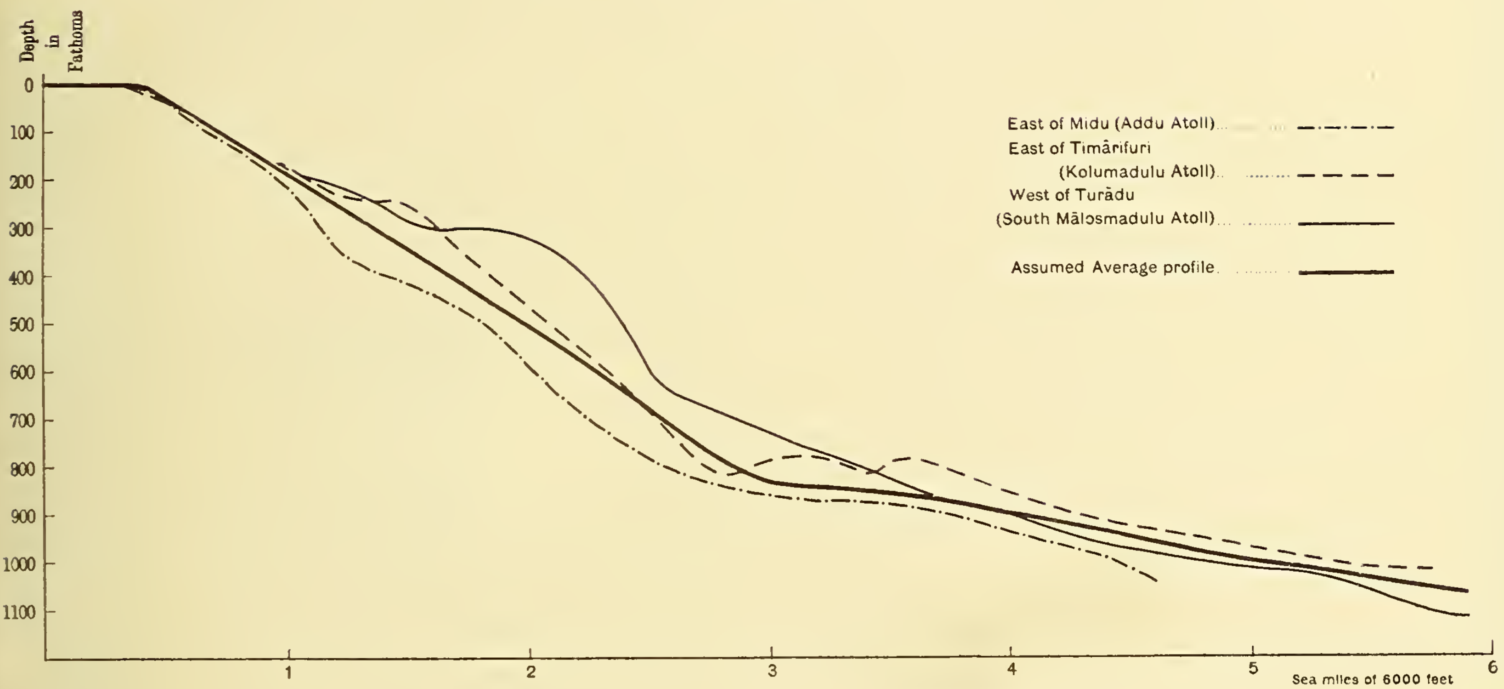
DESCRIPTION OF PLATE I.

Fig. 1.—Seaward profile of Atolls, Maldive Archipelago.

Fig. 2.—Gravity Anomalies, Minikoi and Maldive Sections.

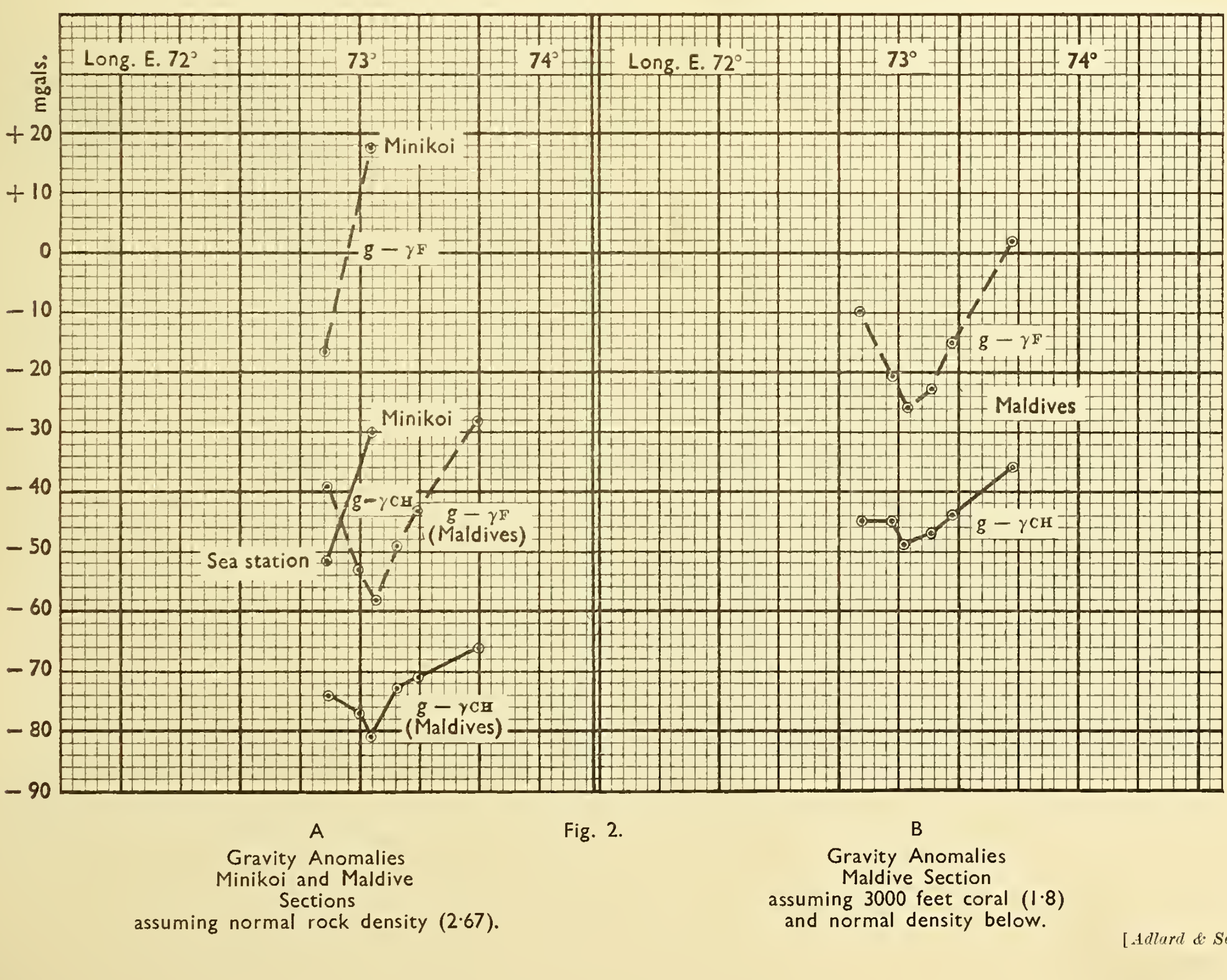
Seaward Profile of Atolls
Maldive Archipelago

Vertical scale twice Horizontal scale



REG No 1470 D.D. 1934–330 Helio 6. I. O. Dehra Dun

Fig. 1.



A
Gravity Anomalies
Minikoi and Maldive
Sections
assuming normal rock density (2·67).

Fig. 2.

B
Gravity Anomalies
Maldive Section
assuming 3000 feet coral (1·8)
and normal density below.

[*Adlard & Son, Ltd. Impr.*

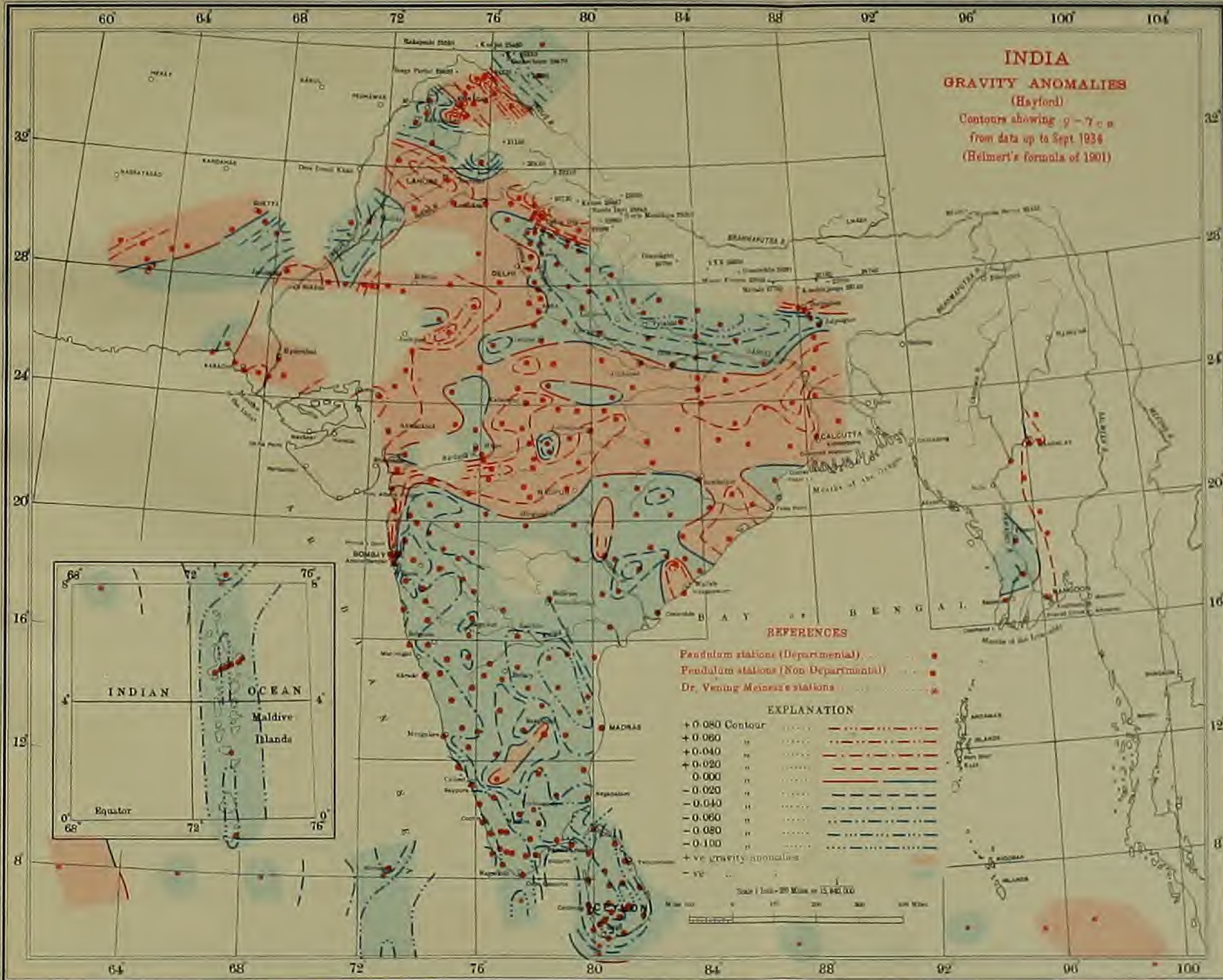
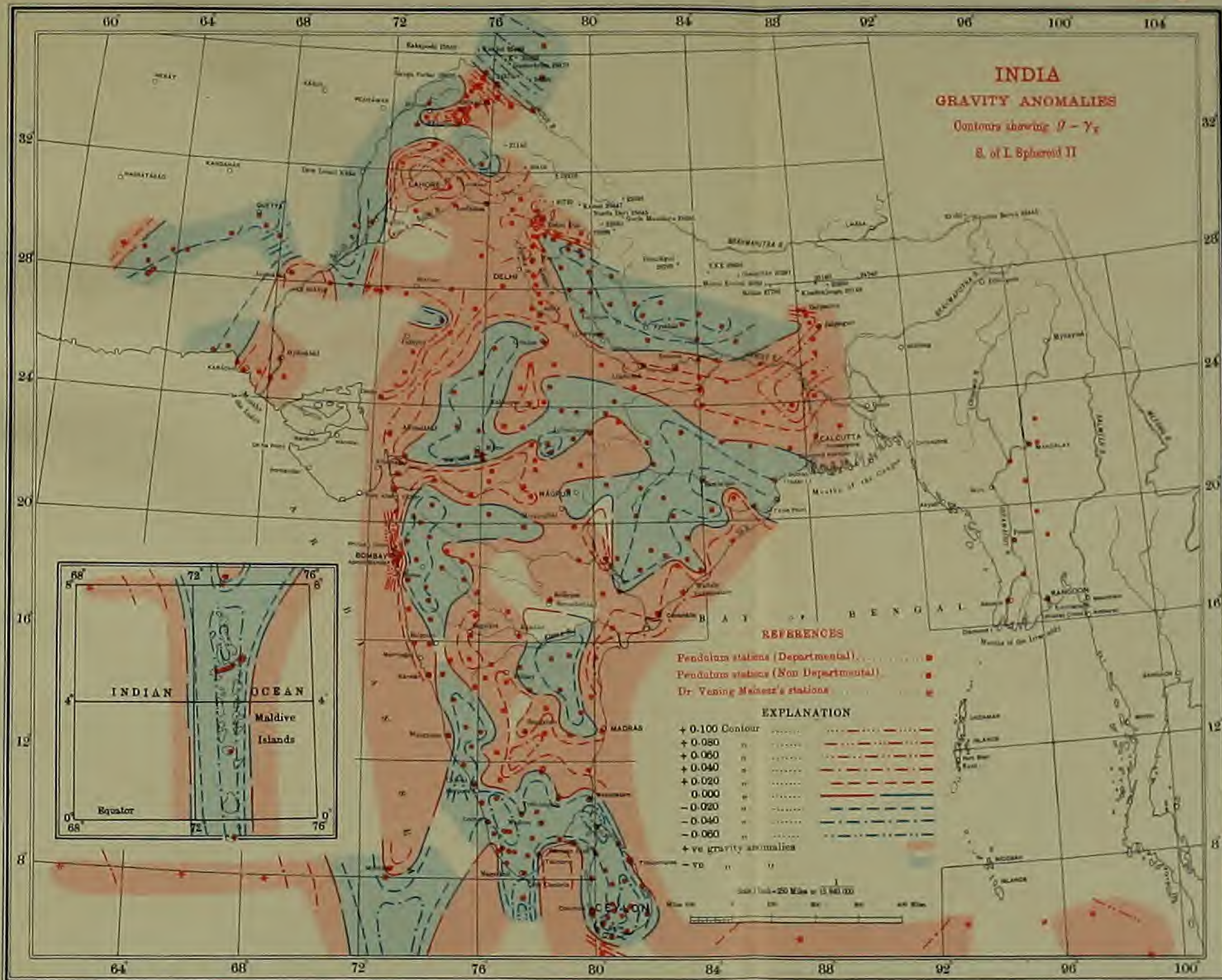

INDIA
GRAVITY ANOMALIES
(Hayford)
Contours showing g − γ c o
from data up to Sept 1934
(Helmert's formula of 1901)
REFERENCES
Pendulum stations (Departmental)
Pendulum stations (Non Departmental)
Dr. Vening Meinesz's stations
EXPLANATION
+0.080 Contour
+0.060
+0.040
+0.020
0.000
−0.020
−0.040
−0.060
−0.080
−0.100
+ve gravity anomalies
−ve
BAY OF BENGAL
INDIAN OCEAN
Maldive Islands
Equator
BOMBAY
CALCUTTA
MADRAS
DELHI
LAHORE
RANGOON
MANDALAY
CEYLON
60° 64° 68° 72° 76° 80° 84° 88° 92° 96° 100° 104°
32° 28° 24° 20° 16° 12° 8°

Chart II



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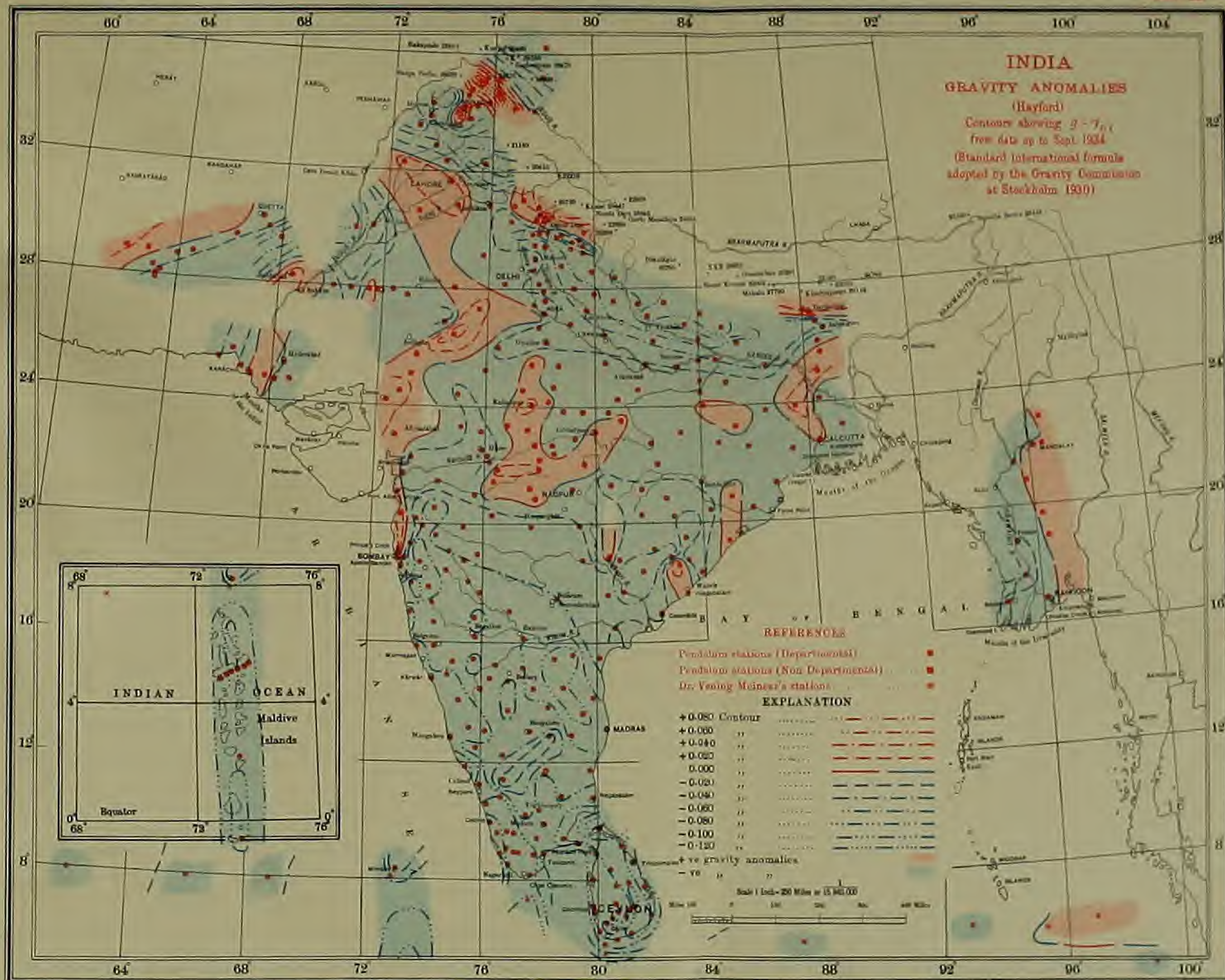
1934


INDIA
GRAVITY ANOMALIES
(Hayford)
Contours showing $g - \gamma_{0.c}$
from data up to Sept. 1934
(Standard International formula
adopted by the Gravity Commission
at Stockholm 1930)
REFERENCES
Pendulum stations (Departmental)
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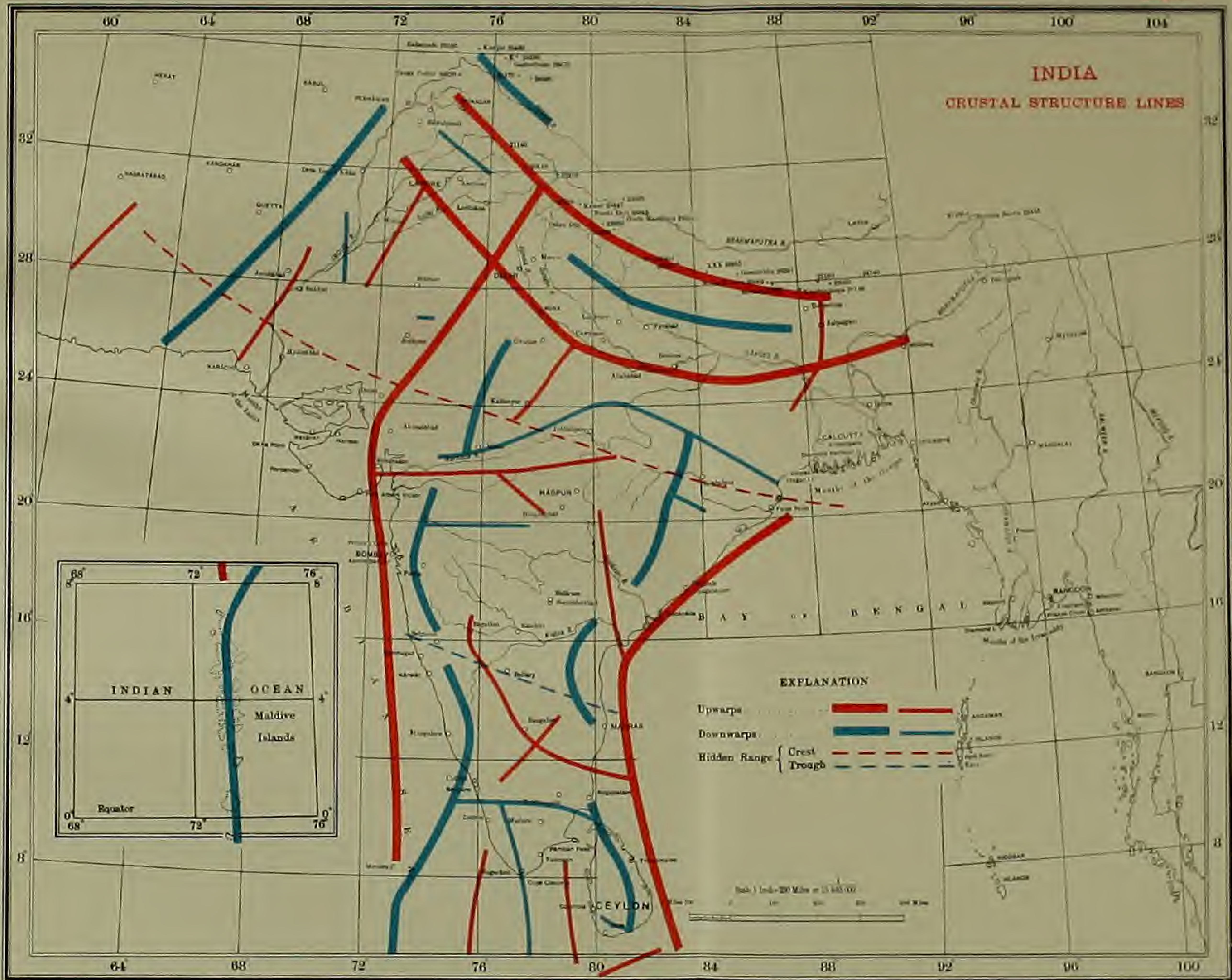
EXPLANATION
+0·080 Contour
+0·060 ,,
+0·040 ,,
+0·020 ,,
0·000 ,,
−0·020 ,,
−0·040 ,,
−0·060 ,,
−0·080 ,,
−0·100 ,,
−0·120 ,,
+ve gravity anomalies
−ve ,, ,,
BAY OF BENGAL
INDIAN OCEAN
Maldive Islands
Equator
BOMBAY
MADRAS
CALCUTTA
DELHI
NAGPUR
LAHORE
CEYLON
MANDALAY
RANGOON
BRAHMAPUTRA R.
Mouths of the Ganges
Mouths of the Irrawaddy
60° 64° 68° 72° 76° 80° 84° 88° 92° 96° 100° 104°
32° 28° 24° 20° 16° 12° 8°


INDIA
CRUSTAL STRUCTURE LINES
EXPLANATION
Upwarps
Downwarps
Hidden Range { Crest
Trough
INDIAN
OCEAN
Maldive
Islands
Equator
BAY OF BENGAL
CALCUTTA
BOMBAY
NAGPUR
MADRAS
CEYLON
RANGOON

BRITISH MUSEUM (NATURAL HISTORY)

THE

JOHN MURRAY EXPEDITION 1933–34

SCIENTIFIC REPORTS

VOLUME I. No. 5

AN ACCOUNT OF HORSBURGH OR GOIFURFEHENDU ATOLL

BY

R. B. SEYMOUR SEWELL, C.I.E., Sc.D., F.R.S.

(Lieut.-Colonel, I.M.S. (ret.).)

WITH SIX PLATES AND ONE TEXT-FIGURE

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WITH SIX PLATES AND ONE TEXT-FIGURE.

This atoll is one of the western series of the Maldive atolls, and lies at the western end of Kardiva Channel, in about lat. 4° 51′ N., long. 72° 55′ E. Owing to its position it lies well within the influence of both the south-west and north-east monsoons, and thus differs considerably from Addu atoll.

Both Stanley Gardiner (1903, p. 377 *et seq.*) and Agassiz (1903, p. 54) have given accounts of the condition of the atoll at the time of their visits, and one is thus able to compare the conditions that were present in 1899 and 1902 respectively with that which was found to exist in 1934, when we visited it during the course of the John Murray Expedition.

The general shape of the atoll is pear-shaped or egg-shaped, with the more pointed end towards the east and its long axis running nearly east and west; the major diameter has a length of approximately ten miles from reef edge to reef edge, and the shorter north to south diameter is about half this. From the position of the atoll one would expect to find that the strongest winds experienced in the atoll during the course of the year would blow from the south-west during the period of the south-west monsoon in June–August; Agassiz has stated that the north-eastern part of the atoll is exposed to the full force of the north-east monsoon, but he seems to have overlooked the fact that the line of the eastern series of atolls and especially Fadiffolu atoll must to some, and possibly a large, extent protect Horsburgh atoll from the full effect of this wind, and Stanley Gardiner is more correct in his statement that the atoll is fully exposed to the south-west and west, but is to some extent sheltered on the north-west by the neighbouring atoll, South Malosmadulu, and especially by its eastern horn, that seemed to him to divert the currents of the north-east monsoon more or less away from the northern reef of Horsburgh. At the same time it must be pointed out that the greatest strength of the wind in this area is, according to the wind-charts published by the Koninklijk Nederlandsch Meteorologisch Instituut (1924–30), usually from a quarter between north-west and south-west, and that it blows from this quadrant almost continuously from April to the end of November.

Month.	Prevailing wind.	Force : Beaufort Scale.	
January	NE	2–3	NE monsoon.
February	NE	2–3	
March	N-E	2–3	
April	NW	3–4	
May	W	3–4	
June	W-SW	3–4	SW monsoon.
July	SW	2–3	
August	W	2–3	
September	W	3–4	
October	NW-W	3–4	
November	W	3–4	
December	N-E	2–3	NE monsoon.

During the periods of the year between the two monsoon seasons the north-west or west wind is more prevalent and blows more strongly. Although it is certain that in different years there will be a considerable range of variation in the meteorological conditions, during the period of our visit to the atoll in April, 1934, the prevailing wind was from the north-west or west-north-west, and the average strength was force 3 in the Beaufort scale. During the occurrence of cyclones in the Laccadive Sea to the east and north-east of the atoll there will be heavy winds from the north or north-west.

The only opening into the lagoon is situated in the western part of the south side of the atoll, so that, if the position be due to the prevailing wind and, therefore, on the lee side of the atoll, as is usually held to be the case, then this wind should be from the north or north-east ; and this would not be in agreement with the observations recorded above. At first sight there seems to be only a single entrance channel. Stanley Gardiner (1903, p. 377) states that there is " only a single passage with 4–6 fathoms of water to the south ", but in reality this entrance is a double one, and is very similar in its general features to the entrances to Addu atoll. On the west side of the apparently single entrance and running close to the reef edge and Mafura Island there is a narrow but deep channel, in which the depth of water is 20–22 fathoms ; this is bounded on the east by an elongate reef, running in a N by E direction, that rises to within $2\frac{1}{2}$ fathoms of the surface, but does not actually reach it. To the east of this submerged ridge there is a second wide but shallow passage, with only 3 to 4 fathoms of water at its outer end, but deepening to a depth of 8 fathoms towards the lagoon. This second wide channel is bounded on the east by the reef on which the island of Fehenfura is situated.

A further resemblance to the entrance at Addu atoll is to be found in the quite distinct tendency for the reef to be prolonged inwards into the lagoon on either side of the entrance. Immediately within the entrance there is an isolated reef on either side ; that on the west is shown in the chart given by Stanley Gardiner (1903, p. 377, fig. 90), as well as in the Admiralty Chart, and opposite the middle of the shallow eastern channel there is a second small shoal, with only some $2\frac{1}{2}$ fathoms of water on it, rising from a depth of about 15 fathoms.

THE OUTER REEF.

In an atoll such as Addu, in which a considerable part of the reef is covered with islands, it is possible to divide the reef into three more or less concentric zones, namely the outer reef flat or boat channel between the reef crest and the islands, the ring of islands, and the inner lagoon reef flat. Such a distinction is, however, only possible in Horsburgh atoll on the north and north-east sides, where a string of islands is still to be found; around the remainder of the reef no such division can be made owing to the complete absence of land from this section of the reef. Stanley Gardiner has tentatively attributed this distribution of the land to the effect of the south-west monsoon that impinges on the south and west sides of the atoll and leaves the north-east part but little affected—a view with which I am in agreement.

Taking the entrance channel as our starting-point, to the west, *i. e.* on the south-west and west sides of the atoll, the reef flat is wide, and extends, without interruption from islands, from the outer margin to the lagoon; there is no very definite lagoon reef, the water gradually deepening to some 20 fathoms as we follow the slope inwards. Only in the vicinity of the entrance channel is there a definite lagoon-reef.

On the north side of the atoll lies a string of three islands, commencing with Inafuri at the north-west point, and continuing with Furadu and Fehendu islands. In this part of the reef the general character of the seaward margin is very different from that in Addu atoll, for here there is no definite " buttress and trench zone ", such as is present in the exposed parts of that atoll. The seaward slope from the reef crest is broad, usually about 20–25 yards across, and it slopes gradually down to the reef edge, which appears to drop steeply into deep water, but near the edge the water was too deep for me to be able to make a careful examination. This seaward zone is characterized by a rocky floor from which arise numerous masses of dead coral, while dotted over the reef flat and growing, sometimes on the rock floor and in other places on these dead coral masses, are numerous small colonies of living coral, mostly compact colonies of madrepore (*Acropora*), but interspersed with colonies of *Cœloria*, Astræaceæ, etc. In this part of the reef there seems to be little or no growth of Lithothamnia—a condition that in all probability is correlated with the protection afforded by South Malosmadulu atoll and the consequent absence of a heavy surf. As one proceeds inwards from the reef margin the masses of dead coral become more and more numerous (Pl. I, fig. 1), till they finally blend together into a zone that might well be mistaken for a " boulder zone ", but a comparison of this area with the true boulder zone in Addu atoll (Pt. III, Pl. II, fig. 3, *supra*) reveals several differences, and the general structure, especially of the seaward zone, more nearly approaches to the condition that was found to be present in the lagoon reef on the north-east side of Addu atoll (Pt. III, Pl. VII, fig. 1, *supra*), where the main mass of the reef consists of dead and partly eroded coral-rock on which numerous small and usually compact colonies of living coral are growing, and the general features are, I think, to be explained as a result of the death of the old reef, consequent on a change of sea-level, and the subsequent erosion of the dead coral down to a depth at which living coral can again acquire and maintain a foothold. In Horsburgh atoll this " boulder zone " is about 8 to 10 yards across and is fully exposed at low water; it seems to be the remains of the old and dead reef, that has not yet been entirely eroded away, augmented to some and possibly to a considerable extent by the addition of masses of coral that have been uprooted during storms and have been rolled inwards

by wave action, the comparatively weak force of which in such a sheltered area is yet sufficient owing to the lesser consolidation of the reef due to the reduced and almost negligible growth of Nullipore. Some of these masses of dead rock or coral were free, but others had either become consolidated with the basic rocky substratum or else had never been detached from it. Beneath the loose coral masses are to be found small Holothurians, irregular Star-fish, Brittle-stars, Sipunculids, *Thalassema* sp., Crabs of various genera, such as *Leptodius* and *Calappa*, Hermit-crabs, small Fish, and Sponges of various kinds, especially the encrusting forms ; but on the whole the fauna is not a rich one.

Inside this zone, and usually clearly and sharply marked off from it, is a wide reef flat or boat channel, some 150–200 yards across, that is covered at low-water spring tides by about 1 ft. to 18 in. of water in the outer part, though the depth increases somewhat as one approaches the islands that in this part of the reef stand some distance back from the reef edge. In places the change of level from the " boulder zone " to the boat channel is abrupt, forming a small precipice. Along the outer part of the boat channel, just inside this " boulder zone ", there is a belt that is characterized by a profuse growth of living coral (Pl. I, fig. 2) ; in places this growth consists almost entirely of colonies of *Heliopora cœrulea*, some of them living but others dead and more or less encrusted with a calcareous deposit, and interspersed among these colonies are other smaller colonies of stag's horn Madrepore and *Pocillopora*, with occasional colonies of Astræaceæ and *Millepora complanata*, these latter being conspicuous by reason of their bright yellow colour ; a fair amount of the calcareous alga, *Halimeda*, is also found here. In other parts of the boat channel the coral growth consists almost entirely of branching stag's horn Madrepore (*Acropora*).

The inner part of the boat channel constitutes a wide flat, the floor of which is composed of rock with a covering of loose sand ; this is largely occupied by burrowing or sedentary animals, among the latter being several large Actinians that, when their tentacles were touched, retracted themselves into holes in the sand about 3 in. in diameter, and examples of the stinging Anemone, *Actinodendron*, were also noticed. Holothurians were comparatively rare, only a few being seen ; but scattered over the flat were colonies of a brownish-yellow Anthozoan (? *Palythoa*) and in places small beds of a brown Tubularian-like Hydroid, while numerous brightly-coloured small fish were to be seen swimming in and out of the coral colonies or darting for shelter beneath the ledges of some piece of dead coral.

At the eastern end of this northern reef flat lies the island of Goidu, and here the so-called " boulder zone " becomes merged in the outer rim of the island. The northern part of this island has been eroded away to form a wide shallow bay, in which the boat channel terminates and large areas of which dry completely at low-water spring tides. At the north-east corner of Goidu Island a spit, composed of rounded coral fragments, runs out from the island and curves round towards the west to become continuous with the " boulder zone " and form the northern boundary of the bay. This spit consists of a basal part of large water-worn boulders, that appear to have been washed inwards across the outer reef flat, and an upper part of smaller fragments with one or two lines of coral shingle. Off the extreme end of the spit on the so-called " boulder zone " are one or two " coral horses ", indicating an earlier extension of the island that has now been washed away. The floor of the bay is composed of sand and mud and is thickly overgrown with a grass-like alga (? *Halophila*), and on one occasion enormous numbers of the

Schyphomedusa, *Cassiopea andromeda* (Forskål) var. *maldivensis* Browne, were found here; they were all lying on their backs with their tentacles waving in the water exactly in the manner recorded by Stanley Gardiner (1906, p. 962). I attribute the luxuriant growth of the weed in this area to the degree of "manureing" that is taking place, for round the head of the bay is a large fishing village.

At the extreme east end on the atoll the seaward edge of the reef lies close to Goidu Island, but to the south of this island the so-called "boulder zone" again makes its appearance and is exposed at low-water spring tides. Outside this part of the zone the surface of the reef is thickly dotted over with irregularly scattered colonies of growing coral of several kinds, conspicuous among which was a very strong and stout stag's horn coral (? *Acropora grandis*), as well as colonies of *Porites*, *Goniastræa* and *Heliopora cærulea*. This outer zone shelves slowly downwards towards the seaward edge of the reef, over which a slight surf was generally breaking: along the edge occasional large raised colonies of a species of branching coral were exposed by the back-wash of the waves, but otherwise the reef edge was never exposed even at the lowest states of the tide. Stanley Gardiner, who examined this area carefully during his visit in 1899, informs me that the coral here is for the most part composed of colonies of *Psammocora* and especially of *Montipora*, the former possessing a yellowish colour, while the latter is greyish. Here again there seems to be no "buttress and trench zone", and the amount of nullipore growth must be insignificant. The so-called "boulder zone" itself here consists of dead and water-worn masses of coral. Inside this zone the reef flat or "boat channel" is covered at low water by 1–1½ ft. of water, and growing on the flat are colonies and masses of living coral of many kinds, among which the "corymbose" type of Madrepore is of frequent occurrence, while small colonies of *Acropora*, Astræaceæ and *Heliopora cærulea* are also present. On the whole the stag's horn type of Madrepore predominates and in places forms large beds, spreading over the surface of the flat towards Goidu Island. The bulk of the reef floor is covered with sand, with occasional lumps of dead and water-worn coral, and a few large yellow Holothurians, as well as some stinging Actinians, *Actinodendron* sp., were seen. To the south of Goidu near the edge of the reef lies a small detached islet, that appears from its position to correspond to the one named Masilokolu on the Admiralty chart. On the "boulder zone" between Goidu and this little islet are one or two coral horses about 1½ ft. in height, that still indicate either the former extension of Goidu Island or the last remaining traces of a second small islet, Raburi.

At the time when I visited the southern portion of the reef the breakers on the outer edge were too heavy to allow me to make a complete examination of the outer zone, but from what I was able to see the seaward margin appears to be very similar to the exposed face of the reef in Addu atoll. Stanley Gardiner (1903, p. 380) states that "the reef flat round the whole atoll is quite similar to that on the west of Minikoi, where no land exists", and the extreme margin is formed by a definite "buttress and fissure zone". Inside the breakers in this part of the reef there is a well-marked true boulder zone, consisting for the most part of small masses of dead and water-worn fragments of coral, some of which have been torn off the face of the reef and have been flung inwards by the force of the waves, though others may have been eroded out of the original coral rock. Some of these fragments are lying loose on the reef, but many of them have become consolidated with the reef flat. Many of these masses are plates and stumps of a type of coral that appears to be identical with that seen on the seaward margin at the east end of this atoll, and on

the face of the lagoon reef at the north-east corner of Addu atoll, namely a very stout stag's horn Madrepore with large flat and thick leaf-like branches (? *Acropora grandis*). Small colonies of *Pocillopora*, *Madrepora*, Astræaceæ, *Cœloria*, etc., are growing on the reef flat, but the predominating feature, as usual in an exposed situation, is the growth of *Lithophyllum*. A few patches of *Halimeda* and other Algæ contrive to maintain their position in spite of the to-and-fro wash of the heavy seas, but for the most part the reef is devoid of vegetation. Scattered along the boulder zone are numerous large masses of coral; according to Stanley Gardiner (1903, p. 380), on this part of the reef to the south of the atoll there are " here and there . . . larger rocks appearently due to elevation ", but the only rocks that I found were large masses of coral, smaller, doubtless, than those found on the reefs of the Pacific atolls, but still indubitably meriting the term " negro-heads ". All these coral masses had in my opinion been torn off the reef face and had been flung up on to the boulder zone; the larger masses lay nearest to the breakers, and the distance to which individual masses had been flung appeared to depend, to some extent at any rate, on their shape, for rounded masses of Astræaceæ had been rolled further inwards across the reef, while irregularly shaped masses had come to rest sooner and, therefore, are now nearer the breakers. I could detect no evidence of elevation in this part of the reef, though there is ample evidence of this in other parts of the atoll, and the whole structure of this region seems to me to be attributable to wave-action and erosion. Stanley Gardiner (1903, p. 377) remarks that " a line of coral rock and two islets to the west of Goidu, together with a series of masses on either side of the passage, prove elevation. A certain number of coral pinnacles, running from Goidu westward in the boulder zone of the reef as far as the passage, indicates that the elevated land once probably extended along the whole south side of the atoll ". Although I could detect no actual evidence of previously existing land on this southern section of the reef, I am in entire agreement with the view that land was formerly present here; but it seems to me that the destructive activity of the south-west monsoon and marine erosion have now completely destroyed the last traces of it; and in this connection it must be remembered that it is exactly this section of the atoll rim that feels the full effect of the south-west monsoon winds and seas. The larger negro-heads, some of which are from 3–3½ ft. in height and from 3–4 ft. in diameter, were in my opinion derived from the reef margin; they lay in any position, many of them being upside down, and were, I am convinced, neither resistant masses of coral rock, nor colonies of coral still *in situ*.

Inside the boulder zone in this part of the reef there is a wide expanse of reef flat, extending uninterruptedly to the edge of the lagoon reef. Immediately inside the boulder zone the flat is thickly covered with colonies of growing coral, for the most part of stag's horn Madrepore, with numerous small scattered colonies of *Pocillopora*, Astræaceæ, etc., and a few scattered *Fungia* and small colonies of *Heliopora cœrulea*. As one follows the reef flat inwards, this growth of coral gradually thins out and the surface of the reef becomes an extensive sand flat, with here and there patches of stag's horn Madrepore, until one reaches the lagoon reef.

THE ISLANDS OF THE REEF FLAT.

As is frequently the case in these atolls, there is on either side of the entrance channel a small rocky islet, that on the west side called Mafura and that on the east Fehenfura. Regarding these Stanley Gardiner (1903, p. 379) states that " they are formed of coral

rock. . . . They represent the same line of rock that occurs to the east of Goidu, and, if clothed with vegetation, would be not dissimilar to Raburi and Masilokolu". Mafura is composed, at any rate in its upper part, of coral fragments, broken and water-worn and black in colour: and this black colour of the fragments suggests that they are not fresh coral masses torn off the reef, but are old masses that have been eroded out of the reef rock and have been subsequently piled up in their present position. There is in all probability beneath these loose fragments a basic stratum of rock, on to which the coral fragments have been flung in much the same manner as they have been flung up in the island of Mulikadu at the south entrance of Addu atoll (Pt. III, Pl. IV, fig. 1, *supra*).

The chief island in the atoll, Goidu, that is situated on the extreme north-eastern part of the reef, still retains what was probably its original position on the "boulder zone". Along the seaward face the island is raised some 3 or 4 ft. above the general level of the rest of the island by a wide bank of coral boulders and shingle, mixed with a certain amount of vegetable mould and debris, that is thickly overgrown with trees and bushes. The rest of the island is flat and consists of sand; it is thickly wooded in the eastern part, but towards the north-west area this thick vegetation thins out somewhat and is replaced by a bush scrub and numerous palm trees. The seaward face of the raised outer margin, which appears to correspond to the "hurricane-beach" of other atolls, though its general features are now somewhat obscured owing to the thick vegetation and the consequent formation of mould, drops steeply for a short distance and then slopes more gradually down to the water level, where it blends with the reef flat (Pl. II, fig. 1). The boulders and coral fragments forming the outer rampart are rounded and water-worn, and appear to be very similar to the water-worn boulders that form the basal part of the spit that runs out towards the north along the so-called "boulder zone" at the north-east corner of the island (*vide supra*, p. 112).

The sloping part of the beach above sea-level consists entirely of a wide expanse of coral rock with scattered patches of loose sand, and here and there are scattered larger blocks of conglomerate that were clearly at one time part of the raised margin of the island, but which, owing to erosion, have now been separated from it. It appears certain that a slow but steady erosion is going on and that the island is being gradually driven back from the boulder zone, though the degree to which the atoll is sheltered from the full force of the north-east monsoon by the atolls of the eastern series has much delayed the process; there is, however, clear evidence of erosion in the presence of fallen trees and shrubs along the beach. Just inside the raised rim is a small lake (kuli), now nearly filled up and much overgrown by bushes, rushes, etc.; around its margin were several examples of the crab *Cardiosoma carnifex* (Hbst.), and these have also honeycombed the inner side of the raised rim with their burrows. In the jungle examples of *Geograpsus grayi* (M. Edw.) are to be found.

On the south-east side of the island there is a wide bay, the northern horn of which is formed by the southernmost part of the raised rim that is continued southwards for a short distance along the "boulder zone" as a spit of coral fragments and shingle. Beyond this to the south there is on the reef flat a group of coral horses and then comes a small islet. These coral horses probably denote a previous extension of the main island, Goidu, the intervening area having since been eroded away. At the time when Moresby made his original survey of the atoll there were two small islets in this position, named respectively Raburi and Masilokolu; both of these are still shown on the chart given by Stanley

Gardiner (1903, p. 377, fig. 90), and were there at the time of his visit in 1899, though he informs me that Raburi was then only a small mass of rocks awash and without any vegetation ; by 1902, when Agassiz paid his visit to the atoll, this latter island had disappeared, for he remarks (1903, p. 54) that " the southern extremity of Goidu Island appears to be wasting away ; a small adjoining island marked on the chart has disappeared." At the time of my visit in 1934 there was only a single islet in this part of the reef, which from its position seems to correspond with Masilokolu, and this too was clearly being eroded away. The outer rampart of coral rock has been breached and much of it has disintegrated, though the more solid part of the rim still resists erosion and is being converted into coral horses (Pl. II, fig. 2), that stand up about 1–1½ ft. above low-water level. Between these raised masses and the present sea-face of the islet is a flat area of boulders, just awash at low water and passing gradually into the island beach, that on the north-east side consists of a coarse coral shingle, but on the south side is still composed of larger water-worn coral boulders. All around the sea-face of this islet are fallen trees and shrubs. On its inner or western face the islet consists of a flat area of shingle that is devoid of trees and bushes and appears to be of quite recent origin ; this slopes downwards to the level of the reef flat, and spreading inwards across the reef flat from the islet is a spit of sand with a margin of coral shingle to both north and south of it, that on the south side being considerably the larger (Pl. III, fig. 1). There can be no doubt that this islet also is rapidly undergoing erosion and will before very long have been completely disintegrated. The small patch of coral horses between Goidu and Masilokolu (Pl. II, fig. 2) may, perhaps, be the last remaining traces of the islet of Raburi. Around the northern part of the bay Goidu Island is also being eroded ; trees and shrubs have been killed and have fallen on the beach. Scattered along the beach are eroded masses of coral rock, and at one point the land has fallen away, leaving a small cliff, some 3 ft. in height, in which one can recognize an upper stratum, about 1 ft. 3 in. in depth, of brown mould and roots of trees, and below this is a horizontal layer, about 1 ft. thick, of sandstone. Still further to the south on the south-east side of the island one comes to an area in which the land appears to be extending ; here the line of the shore bends outwards towards the reef flat, and between the thick jungle, with which this part of the island is covered, and the sea beach there is a margin of flat sandy ground that is covered only with low shrubs and saplings. Along the upper part of the beach in this area is a line of small pumice fragments. If we assume that these fragments were originally derived from the explosion of Krakatoa in 1883, it is highly unlikely that they were shortly afterwards thrown up in this part of the beach, as seems probably to have been the case on some of the lagoon beaches in Addu atoll ; it is still less likely that they could have been deposited here after some earlier eruption, and it is more probable that this is a comparatively recent deposit of old fragments that were originally flung up on some other part of the island, and that during the process of erosion they have been displaced and have been re-deposited in the present situation. On the north side of Goidu, behind the spit of coral boulders that runs out on to the reef flat, the island, as already pointed out, has been eroded away to form a wide bay. As one walks westward along the shore of this bay towards the north-west corner of the island one sees numerous outcrops of beach-sandstone, and the beach, which otherwise is composed of sand, slopes upwards towards the island and terminates in a small cliff, about 2 ft. in height. Along this part of the island there is no raised rim ; the land is

flat, and is covered with a bush scrub and plantations of palm trees. Near the north-west corner of the island there is an area of the beach that is traversed by a number of roots of trees, running out from the island into the sea, and on the west side of this area is a small sand spit that forms the extreme north-west corner of the island. Immediately round the corner on the west side there is again an outcrop of beach-sandstone, and along the southern part of the west beach and at the south-west corner of the island an extensive exposure of the same formation is to be seen. There can be little doubt that on the whole the island is steadily being eroded away and, although there may be a small gain from time to time in one or other part of the island, the main change seems to be one of loss.

On the northern part of the atoll rim to the west of Goidu, but separated from it by a wide shallow channel, lies the island of Fehendu. This island lies a long way in from the reef margin and is long and narrow, especially near the middle of its length, so that it exhibits a very elongate figure-of-eight or " dumb-bell " shape. It is thickly wooded, and on its eastern half is situated a large village. The east end of the island shows clear evidence of erosion ; at the south-east corner there is an outcrop of rock, that borders the southern or lagoon shore of the island, and is continued on for some 15 yards as a reef that continues the line of the shore and runs eastward towards Goidu Island. At the north-east corner of the island there is a sand spit that also runs eastward ; so that between the rock reef and the sand spit there is formed a small bay, the floor of which is for the most part sandy, but which is dotted over with scattered boulders and slabs of sandstone. Above the beach the island here terminates in a cliff that exhibits the structure that one so frequently finds in these coral islands, namely an upper stratum of brown vegetable mould and tree roots, about 1 ft. 3 in. in depth, below which there is a thin layer of loose white sand ; and then below this again comes a horizontal stratum of sandstone, about $1\frac{1}{2}$ ft. thick, below which the sand is again soft. One cannot but conclude that the slabs of sandstone in the small bay have been derived from the erosion and undermining of the sandstone stratum of the island. Along its northern side the island is edged with a sloping sandy beach, at the foot of which near low tide mark there is for long stretches a belt of coral rock ; but about the middle of the length of the island and opposite its narrowest part this rock belt has been breached, and much of the land has been eroded away to form a wide bay (Pl. III, fig. 2). It is very interesting to note that Stanley Gardiner makes no mention of this bay in his account of the island. At the time of our visit it formed a very noticeable feature and, combined with a corresponding bay on the south side of the island (*vide infra*, p. 119), the effect has been very nearly to divide the island into two parts. It is possible that at the time of Stanley Gardiner's visit in 1899 there was no such bay ; erosion on the seaward face appears to have proceeded here with remarkable rapidity, for the Head Man of the atoll, who seemed to be a very intelligent individual, informed me that when he first came to the atoll, now some twenty-three years ago, and eleven years after Stanley Gardiner's visit, this now very narrow neck of land separating the seaward and lagoonward beaches and connecting the two ends of the island was about 40 yards wide, whereas at the time of my visit in 1934 it was only some 4–5 ft. in width.

Along this eastern part of the island and round the shores of the bay the beach is sandy and slopes up gradually to the level of the island ; at low tide numerous rays come close inshore, and, covering themselves with sand so that they are almost unrecognizable, lie basking in the warm water. Along the eastern half of the bay and the neighbouring

part of the northern beach there are several bushes now standing well out on the beach between tide-marks, and the outermost are already dead or are in the process of becoming so. On the west side of the bay the shore runs straight out towards the reef flat and terminates in a short rock reef that runs eastward along what must have been the old shore line, and that is clearly a direct continuation of the original rock margin that still borders the seaward face of the western half of the island. At this point erosion has been active, as is shown by dead and fallen trees on the beach ; here the beach consists of a sloping outcrop of coral rock, above which there is a narrow shelving area of loose sand, and then comes a sheer cliff, about 4 ft. in height, rising to the level of the island (Pl. IV, fig. 1). An excavation was dug into the face of this cliff in order to expose the strata, and here again we can distinguish the same strata that we found on Goidu Island and at the eastern end of Fehendu. The upper 18 in. consist of soil and the roots of trees, etc. ; then comes a layer of loose white sand of about the same depth, below which there is a band, running horizontally in conformity with the general level of the island, of sandstone of a greenish colour and about $1\frac{1}{2}$ ft. in thickness ; below this sandstone there is again a stratum of loose white sand down to the level of the top of the beach. The layer of sandstone exposed in this cliff is almost certainly continuous throughout the whole of the island, for near the village at the east end of the island a well has been dug, and the strata exposed in the process agree exactly with those seen in the face of the cliff ; on the surface there is a stratum about $1\frac{1}{2}$ ft. thick of soil and vegetable mould, and below this comes a layer of compact white sand ; below this again the sand becomes harder and was dug out in lumps, which, however, were not sufficiently consolidated to be termed sandstone, since the lumps could be crushed by hand. This stratum was succeeded by a second layer of loose sand, and then came the rock basis of the island, the old coral rock. It seems probable that in this instance the sandy layer was in the process of undergoing consolidation and in time would have hardened to a true sandstone—a process that would probably be expedited by exposure to the air or spray from the breaking waves on the shore, as in the case of the outcrop on the cliff face.

To the west of the bay the northern margin of Fehendu island is characterized by an almost continuous outcrop of dark grey rock that has been eroded on its seaward face to form a small irregular cliff (Pl. IV, fig. 2) ; the upper surface of this rock ledge has been weathered into numerous holes and pinnacles, but its general level slopes gradually downward towards the island, and here too in places there is a small cliff, where the inner part of the rock ledge has been eroded away by sea action. Finally this rock outcrop disappears beneath the sandy upper part of the beach, which slopes upwards towards the island margin, and at the top of this beach there is a second outcrop of rock, the exposed margin of the sandstone stratum that has been formed beneath the sandy part of the island. In his account of this island Stanley Gardiner (1903, p. 378) remarks : " To the north or seaward side the whole shore is studded with lines of beach sandstone which generally are separated by areas of loose sand. Often, however, the lower terraces lie on the sand flat quite beyond the slope of the beach ; in one place eight separate terraces having been found." For a long time I found it a matter of great difficulty to reach a decision regarding the exact nature of this grey rock along the beach, and I was myself at first inclined to regard it as beach-sandstone, but the general character of the rock, that is composed of a very hard matrix in which are embedded fragments of coral, *Tridacna* shells, etc., is very different from that usually found in a beach-sandstone, and I am convinced that it is in

reality a part of the old raised reef flat, that since its elevation has been protected by the sand of the island, and is now being gradually exposed and eroded along its seaward margin by the combined action of rain and marine erosion. In addition to the breach opposite the bay referred to above, there is another point on the northern side of the west part of the island where this outer rampart of rock has been breached, and here there is now a smooth glacis of rock extending up to the edge of the jungle ; while for some distance along the edge of the jungle at this point are broken-off masses of sandstone, that appear to have been derived from the horizontal stratum of sandstone that has formed beneath the surface of the island and to which I have already called attention (*vide supra*, p. 118). At the west end of the island on the north side a very considerable change appears to have taken place during the past thirty years, for Stanley Gardiner in his account (1903, p. 378) states that " at the extreme west point a sand spit stretches out for 50 yards, with a number of sandstone masses along its seaward face and off its end, showing that the island must have at one time extended considerably further along the reef ". At the present day the tide sets off the outer reef flat round the west end of the island into the lagoon in a strong current that is continually wearing away the sandy beach, that at this point now runs out in a small promontory ; off this spit there is a channel, 5–6 ft. in depth, the floor of which is dotted over with small colonies of growing coral, mostly Madrepore. Lying some distance off the end of the spit on the other side of the channel but in the continuation of the main line of the island is a small sand cay with a few rock boulders. On the south side of the island the beach is, in the western part, composed of a smooth " glacis " of rock (Pl. V, fig. 1), extending from just above high-tide level to low-water mark ; at the low-tide level this outcrop of rock ends in a small but steep and irregular cliff, about 1 ft. in height, that along its margin presents a number of small gullies, reminiscent in miniature of a " fissure zone ". Along the high-water level the rock is eroded into holes and pinnacles, exactly as is the rock of the seaward face of the island. Above this rocky outcrop lies a strip of sandy beach that slopes up to where the vegetation of the island begins. This rock, like that on the outer or seaward face, I take to be part of the old reef rock, that was formerly covered by the sandy part of the island and that has now become exposed and is being steadily eroded away. About the middle of the island, opposite where the bay has been formed on the northern face, there is a corresponding shallow bay on the south side. Along the shore of this bay in its central part there is an exposure of rock, the origin of which is somewhat difficult to determine ; on the lower slope of the beach between tide-marks there is an exposure of dark grey rock that is much eroded, and presents several layers or strata that slope downwards towards the lagoon, and this I take to be a continuation of the similar rock that fringes the northern face of the island and forms the smooth glacis along the western half of the lagoon side ; but above this near the top of the beach there is a second outcrop of rock in which the slope seems to be downwards towards the north and thus away from the lagoon. This latter rock is also somewhat pitted on its upper surface, though not as markedly so as the old rock of the seaward side, and appears to be composed of several strata (Pl. V, fig. 2). I am of the opinion that this is not the same rock as the lower rock exposure on the northern beach or the glacis of the lagoon margin, but is a part of the sandstone basis of the island that has been consolidated beneath the " reverse " slope of the lagoon mound, and has subsequently become exposed by the erosion of the lagoon side of the island ; it is, in this connection, interesting to note that, although there is no

trace of any lagoon mound along this part of the south beach, a little further to the east there is a distinctly raised rim along the island face.

To the west of Fehendu there is a wide interval and then comes the island Furudu, off the eastern point of which there are several sand cays. Furudu is fairly thickly wooded, especially in its eastern part, where there are a number of large trees, as well as smaller bushes; but the western part is in the main covered with a bush scrub. At the extreme east end the island is produced in an S-shaped sand spit that runs out from the island in an easterly direction and is covered for about half its length by a line of low bushes, but beyond this there is only bare sand. In this eastern part of the island both north and south beaches are shelving, and there is no raised rim to the island. The whole of this part of the island is clearly being eroded away, and in one or two places there is an exposure of the horizontal sandstone basis of the island; one such exposure is well seen near the village and there are several more towards the west, in which the sandstone stratum has been clearly undermined, the soft sand beneath it having been washed away. This sandstone stratum is seen to be about $1\frac{1}{2}$ ft. in depth, and lies below a layer, some 2–3 ft. thick, of soil and vegetable mould. In places this stratum consists largely of fragments of broken coral, mainly of either the stag's horn or the "corymbose" type of Madrepore, intermixed with shells, among which was a species of *Oliva*; such a composition suggests that the conglomerate has been derived from the consolidation of sand and coral fragments, such as might originally have been thrown up and have formed part of the reef surface or a sandy beach before the relative elevation of the land took place. Below this outcrop of sandstone there is a sloping sandy beach that terminates below in a wide expanse of solid grey rock, which further to the west forms a raised rim similar to that seen in Fehendu Island. The surface of this lower stratum is weathered and pitted, and the strata of which it is composed can be seen to slope downwards towards the island and away from the ocean face of the atoll. Stanley Gardiner (1903, p. 379) has called attention to this outcrop: "Perhaps the most noticeable point about Furudu lies in its beach sandstone to the north being but little terraced. It presents in many places a cliff of 2 or 3 ft. to the sea with one solid mass of rock behind. . . . The sea has not over-topped the sandstone, and its removal must be by the undermining action of the water, both erosion and solution, just as a pinnacle of coral rock is worn away." In places this grey rock contains fragments of coral, and in one place I found a colony of stag's horn madrepore upright, *in the natural position of growth*, and in a remarkable state of preservation, the calices being little, if at all, worn; there can, I think, be little doubt that this rock is not beach sandstone, but is part of the old reef rock that is now being eroded away. Towards the western part of the island the sea has eroded a considerable part of the north face of the island, so that here too a shallow bay has been formed; and between this bay and the outer reef flat there is a line of rock running obliquely across the reef flat towards the west as far as the so-called "boulder zone" (Pl. VI, fig. 1). At its extreme end and on its seaward face this rocky promontory terminates in a vertical cliff; the rock is clearly composed of a solid stratum that slopes downwards towards the south and away from the reef flat. In places, and especially along the crest, the upper surface of the exposure has weathered, like the rocky outcrop along the sea beach, into pinnacles and holes; but the greater part of the exposure and especially the landward slope is smooth, though traversed by channels, and in places worn into pot-holes in which small pools of water are left by the receding tide. Here again there is some difficulty in reaching

a decision regarding the exact nature of the rock. Is it part of the coral rock of the old raised reef flat ? Or is it an exposure of sandstone, that has been consolidated beneath the "reverse" slope of the seaward margin of the island and has subsequently become exposed by a process of erosion ? I think that one must decide in favour of the former origin. In the shallow water on either side of this rock promontory are several circular masses of *Porites* and numerous colonies of *Heliopora cœrulea*, with occasional patches of *Halimeda*. In a number of instances the upper surface of these *Porites* colonies has been completely killed off, the process being due to or at least accompanied by a deposition of calcium carbonate, the only part of the colony that is still living being the outer margin (Pl. VI, fig. 2). On the inshore side of the promontory the floor of the reef flat is composed of slabs of rock beneath which and partially concealed lie numerous black Holothurians (*Holothuria atra* ?), many of them harbouring a black Polychæt worm, *Polynoe* sp., and numerous Brittle-stars. Along this rock outcrop, as also along the face of the rock outcrop on Fehendu Island, are numerous green grapsoid crabs, *Grapsus grapsus* (Linn.) and *Grapsus strigosus* (Herbst.), and, as the tide rises, small eels and occasionally a small octopus can be seen moving along the face of the outcrop in search of these crustacea. Proceeding westward towards the extreme west end of the island the shore is for the most part composed of a smooth slope of pure sand that is frequented by Ocypode crabs, *Ocypoda ceratophthalma* (Pallas) Ortmann, and is also a favourite locality for turtles that come up to lay their eggs. In one part there is a small outcrop of true beach sandstone between tidemarks, and this is haunted by a number of examples of *Onchidium* sp. The extreme west end of the island forms a long sandy spit, that terminates in a steep slope, off which there is a comparatively deep channel, some 6 ft. in depth. On the south side of the island the land near the west end appears to have been increasing within recent times, for here there is a narrow strip, about 5–6 yards wide, and some 300 to 400 yards in length, that is covered with a species of grass and is dotted over with saplings ; while behind this belt the island is covered with a thick jungle. This recently added strip, however, terminates on its lagoon face in a small cliff, about $1\frac{1}{2}$ ft. in height, that drops to the sandy beach, and this has undoubtedly been formed by a still more recent process of erosion. Opposite the central part of the island there is at the top of the beach a cliff of about the same height, with fallen trees and the exposed roots of others ; and here a line of rock runs along the inner reef flat parallel to the beach and about 30 yards out from the shore. Further to the east the level of the island again terminates in a small cliff, but in this part only about 9 in. in height, and below this is a sloping beach of fine sand, with here and there small outcrops of rock, but not a continuous ridge such as one finds on the northern face ; on the beach were numerous hermit crabs, the cuttle-bones of *Sepiella indica*, shells of *Spirula*, *Pinna squamifera* and other mollusca, mixed with fragments of coral and *Tubipora musica*. Towards the east end of the island near the village there stands on the lagoon beach a large mass of dead coral that is clearly *in situ* ; it is about $2\frac{1}{2}$ ft. in height and its top is dome-shaped. The upper surface shows little or no sign of wear or weathering, and one would infer from this that it became covered, while still alive, or only very recently after death, by the sand ; the freshness of the septa and the absence of erosion of the calices of the upper surface also suggest that its re-exposure must have been comparatively recent. This coral mass, like a ship's bollard, is embedded in the present sandy beach but is actually a part of the rock sub-stratum, that appears as an outcrop on the beach a few yards further to the east of it, so

that the mass would appear to have been a part of the original reef flat on which this mushroom-shaped coral pinnacle was growing before an alteration of sea-level raised it above the water-line.

To the west of Furudu lies the small island of Inafuri. This has a structure similar to both Fehendu and Furudu ; and between Furudu and Inafuri are a number of scattered sand cays.

THE INNER REEF FLAT.

The general character of the inner reef flat and the lagoon reef differs markedly in different parts of the atoll. On the west side, where the atoll rim is devoid of any traces of land, the lagoon floor drops from about 2 fathoms down to a depth of 5–7 fathoms, and beyond this the depth slowly increases to 20 fathoms at a distance inwards of about 1600 yards, the 10-fathom line being nearly mid-way between the reef and the 20-fathom line.

On the north side of the lagoon inside the islands Furudu and Fehendu the floor of the reef also slopes down gradually. As one proceeds towards the lagoon from the island beaches the floor of the reef is at first composed of sand, but, as one gets away from the islands, colonies of coral begin to make their appearance and get gradually more numerous. These coral heads get larger and larger until they constitute an area of " foul ground ", which is closely dotted over with shoals and patches of coral that rise from a depth of about 6 fathoms almost up to the surface. The character of the lagoon floor also undergoes a change : in the inshore region it consists of a somewhat coarse sand, but as we proceed deeper towards the centre of the lagoon the deposit becomes almost a coral mud, mixed with the remains of pteropods, larval molluscs, spicules of Alcyonarians, etc. Along the lagoon margin of this area of foul ground from Inafuri to a point opposite the middle of Furudu island there is an interrupted reef, that is covered with growing coral and that in many places nearly, though never quite, reaches the surface. On the lagoon side of this reef the depth increases suddenly to some 15 or 18 fathoms. The general character of the corals in this area shows a clear transition ; on the lagoon reef and in the neighbouring zone of the foul ground are masses of *Porites*, *Cœloria*, Astræaceæ, and a very stout form of branching madrepore (? *Acropora grandis*) ; in the intermediate zone we find Astræaceæ, Madrepore colonies of the " corymbose " type, *Pocillopora*, etc., while in the inshore region, where the bottom is for the most part sandy, there is little except the ordinary stag's horn Madrepore, interspersed with an occasional mass of *dead* Astræaceæ. Even in the deeper shoals much of the coral is dead ; in a colony of stag's horn Madrepore the basal stalks and the proximal parts of the main branches are usually dead and encrusted with small colonies of Lithothamnion, Sponges, etc., while only the smaller terminal branches are still living.

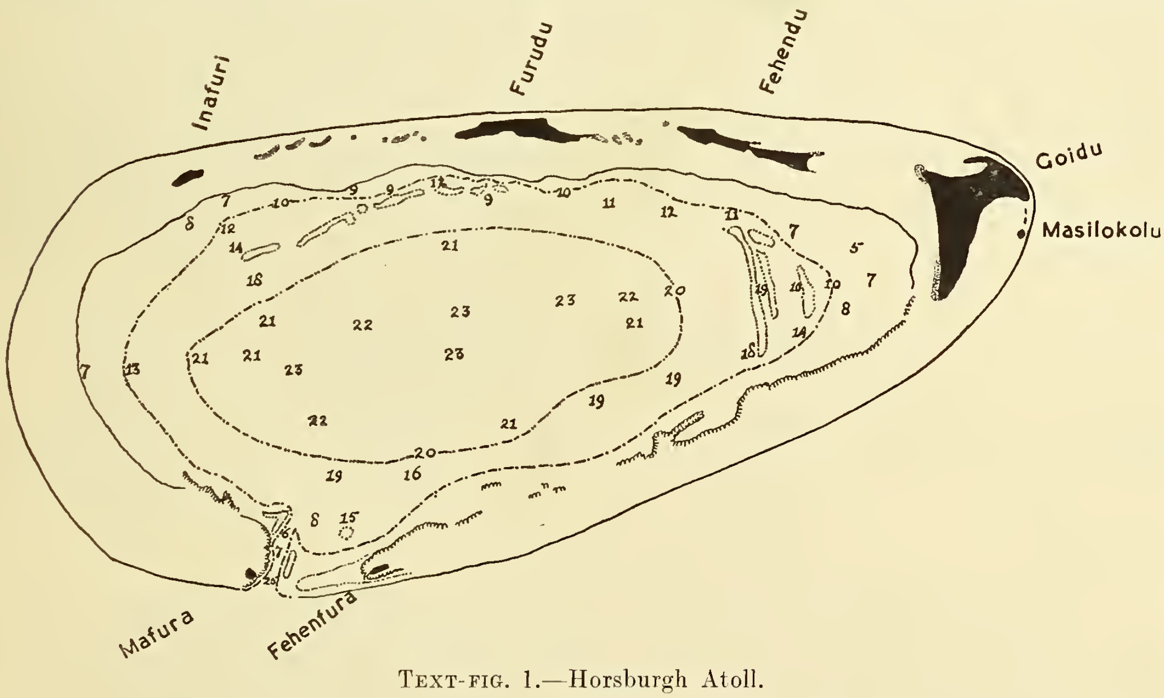
Opposite the eastern end of Furudu and the west end of Fehendu Islands this reef is absent, but on the east side of the lagoon opposite Goidu Island the inner reef flat again presents much the same general character, though here, instead of a single line of interrupted reef, there are no less than three, running more or less parallel to one another, and rising from a depth of some 12–16 fathoms up to 5 to 7 fathoms and in places almost to the surface. As one approaches the west side of Goidu island these reefs are succeeded by an area of foul ground that ultimately is replaced by a wide sand flat, over which the water gradually shoals from about 10 fathoms near the reef to the island beach. In one

area of this flat near the north-east corner of the lagoon there were large numbers of a large yellow Holothurian, about one in every two square yards ; the rest of the flat was dotted over with the ejected sand piles of some burrowing organism.

On the south side of the lagoon, where there are no islands, a typical lagoon reef is present in the greater part of its length, and rises steeply from a depth of some 8 fathoms to within about $2\frac{1}{2}$ fathoms of the surface, after which it shoals up gradually to the level of the reef flat : in this part the reef presents most of the characters that we have seen to be present in the lagoon reef in Addu Atoll. A little to the east of a point midway between the south end of Goidu Island and the entrance channel a long spit of the reef runs almost due east, parallel to the main reef, but separated from it by a bay in which the water has a depth of about 9 fathoms. In this region the reef rises close up to the surface and is thickly covered with numerous colonies of Madrepore of the " corymbose " type, while off the end of the spit are several smaller isolated patches of the reef of the same type. Even in this reef, however, there is an area lying between the part just described and the entrance channel, where consolidation of the lagoon reef appears to have been incomplete. Here the reef, which is well defined on either hand, is interrupted, only isolated patches being formed, and in the same zone the 10-fathom contour line exhibits a very clear bend inwards towards the centre of the lagoon.

THE LAGOON.

As already pointed out, there are segments of the lagoon margin in which the lagoon reef is incomplete, and the lagoon floor shoals gradually upwards to the margin. Stanley Gardiner (1903, p. 377) gives it as his opinion that " the lagoon is increasing at the expense



Text-fig. 1.—Horsburgh Atoll.

of the encircling reef ". A study of the chart of the atoll (Text-fig. 1) shows very clearly that around the west and south sides of the atoll there is a complete absence of land, so that, if we accept the view that there was a general fall in the sea-level some 4000 years

ago, and that this brought the atoll reef above the water line and thus created an almost complete land rim round each atoll, we must also conclude that on these sides of Horsburgh atoll this land rim has now been completely destroyed, the only land now present in this half of the atoll circumference being the two islets, Mafura and Fehenfura, that lie on either side of the entrance channel and are, at any rate in the main, of secondary formation. Furthermore, it is only along the greater part of this segment of the atoll that we find any definite lagoon reef on the inner side of the reef flat.

Around the north and east segment of the atoll we still have a chain of land masses and sand cays, a scattered remnant of the original land ring that was once, in all probability, continuous ; and there is clear evidence that, although around this arc erosion has not yet been completed, this process is steadily going on in each of these islands. It is around this north-east segment of the lagoon that we find an area of " foul ground " that shelves gradually up to the island beaches and that is bounded on its lagoon side by an interrupted reef, rising from a depth of some 10 fathoms or more and crowned with living coral colonies ; furthermore, it is extremely interesting to see that at the south-east side of the lagoon this " foul ground " and its inner reef lies well within the present line of the true lagoon reef. I have already pointed out that in the north-east corner of Addu atoll the process of erosion of the islands appears to have been accompanied by an extensive deposition over the lagoon reef of sand and mud, the result of which has been to cause a gradual destruction of the original lagoon reef and the formation of an area of " foul ground " ; it seems clear that an exactly similar process is and has been going on in Horsburgh atoll, and the conclusion that the absence of a true lagoon reef is, at least in part, directly attributable to the erosion of the land seems to be irresistible. As a result of such erosion sand and mud will be swept inwards with each rise of the tide, and will be deposited over the living corals and Lithothamnion, if any be present, that are growing on the reef surface ; at the same time another effect of the presence of islands and land masses will be to hold up the water over the outer reef flat during the fall of the tide, so that this will undergo a rise of temperature and a consequent increase of evaporation and rise of salinity. On two occasions I took samples of the surface water in three localities on or near the reef for the purpose of comparison, and the results obtained are given below :

Position	Middle of boat channel, N. of Fehendu Is.	Middle of lagoon reef flat, E. of Fehendu Is.	Lagoon, NE. area.
Depth	2 ft.	2 fathoms	10 fathoms
Salinity (*a*)	35·79	35·70	35·70
,, (*b*)	35·23	..	35·03
Temperature	36·5° C.	..	30·5° C.

Such a marked rise in the temperature of the water over the reef flat would certainly have a deleterious effect on the growing coral colonies, while simultaneously, owing to the stagnation of the water on the reef flat during slack water, there is produced, in all probability, a marked deficiency in the oxygen content of the water, though of this I have no direct evidence.

At the extreme west end of the lagoon, where the atoll is exposed to the full force of

the south-west monsoon, we find an absence of land and yet a complete absence of a definite lagoon reef: at first sight this might be thought to disagree with the view expressed above; if, however, one remembers that the deposition of sand and mud on the inner reef flat and the lagoon reef must, owing to the position of the islands that are now undergoing erosion, *i. e.* on the north and east sides of the atoll, mainly occur during the north-east monsoon and, therefore, will be taking place on the south-west side of the site of erosion, the absence of a true lagoon reef on the west side of the lagoon can be correlated with the erosion that is now going on in Inafuri and Furudu Islands and in the reef between them, where there are still a number of sand cays that have not yet been completely swept away.

Another interesting feature of the lagoon that is clearly brought out in the chart is the manner in which the floor gradually slopes upwards from the centre of the lagoon to the reef. In the central part the depth of water is some 23 fathoms, but around the whole circumference the 20-fathom line lies well inside the 10-fathom line, the average distance separating them being, throughout the greater part of the circumference, about half a mile. It is thus clear that the bottom of the lagoon is in this case far from being flat and is actually basin-shaped. This is especially well shown in a section from west to east along the major diameter of the atoll.

Stanley Gardiner (1903, p. 377) remarks that, so far as the published charts indicate, the lagoon "is singularly open, no trace of coral growth, except near the encircling reef, nor of shoaling being anywhere found"; certainly no shoals approach sufficiently near the surface for their presence to be indicated by a change in the colour of the overlying water, but the very small number of soundings that are shown are quite insufficient to warrant the assumption that there are no shoals to be found anywhere.

The bottom deposit over the greater part of the lagoon floor consists of a soft light grey or cream-coloured mud. A sample of this was collected near the centre of the lagoon and was submitted to the Geological Survey of India for examination. The report on this sample is as follows: "Examination by the petrological microscope shows that the specimen forwarded by you is a crystalline aggregate and not amorphous. Boiling for a few minutes with cobalt nitrate shows that at any rate a good deal is aragonite. The specific gravity is, however, low—2·75. But from the nature of the specimen too much reliance need not be placed on this result. It is probably either a mixture of aragonite and calcite or mostly aragonite. The specimen has been analysed and found to contain 0·26% SiO_2." Large samples of the bottom were obtained by means of the grab in both the north-east and north-west parts of the lagoon, and it is interesting to note that the sample from the north-west area contained an appreciable quantity of sulphuretted-hydrogen gas, the proportion being 7·73 mgrm. per litre in the occluded water that was withdrawn from the sample by aspiration.

BIBLIOGRAPHY.

AGASSIZ, A. 1903. The Coral Reefs of the Maldives. Bull. Mus. Comp. Zool. Harvard, XXIX.

GARDINER, J. STANLEY. 1903. The Fauna and Geography of the Maldive and Laccadive Archipelagos, Vol. I. (University Press, Cambridge.)

1906. *Op. cit.*, Vol. II.

KONINKLIJK NEDERLANDSCH METEOROLOGISCH INSTITUUT. 1924–30. Oceanographische en Meteorologische Waarnemingen in den Indischen Oceaan, Publication No. 104, and Supplement, No. 104*a*.

DESCRIPTION OF PLATE I.

Fig. 1.—Outer zone of reef flat opposite Fehendu Island.
Fig. 2.—Inner zone of reef flat opposite Fehendu Island.

FIG. 1.

FIG. 2.

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DESCRIPTION OF PLATE II.

Fig. 1.—Seaward beach on east side of Goidu Island.
Fig. 2.—Seaward face of Masilokolu Island.

FIG. 1.

FIG. 2.

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DESCRIPTION OF PLATE III.

Fig. 1.—Inner beach of Masilokolu Island.

Fig. 2.—North beach of Fehendu Island, looking east.

FIG. 1.

FIG. 2.

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DESCRIPTION OF PLATE IV.

Fig. 1.—Excavation in cliff face to show sandstone stratum.
Fig. 2.—North beach of Fehendu Island, looking west.

FIG. 1.

FIG. 2.

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DESCRIPTION OF PLATE V.

Fig. 1.—Lagoon beach on west end of Fehendu Island.

Fig. 2.—Sandstone outcrop on lagoon beach of Fehendu Island.

FIG. 1.

FIG. 2.

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DESCRIPTION OF PLATE VI.

Fig. 1.—Outcrop of coral rock on north side of Furudu Island.
Fig. 2.—Coral growth on outer reef flat opposite Furudu Island.

FIG. 1.

FIG. 2.

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